Appendix D:
Antennas

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1 Antenna Subproject Specification

1.1 Introduction

Early testing within the VSC project had involved a sizeable and wholly unrealistic antenna for automotive usage, and was originally selected for its wide availability (802.11a Access Point antenna) and DSRC-like frequency range. For roadside units (RSUs), the physical characteristics of these antennas would not likely be an issue since infrastructure mounting usually has few packaging or styling needs. The antennas, though, could not fully answer the question of communication range for on-board units (OBUs) since their protruding nature and frequency-optimization would not mirror likely automotive, production DSRC antennas. Therefore, CAMP-VSCC set about investigating alternative OBU antenna designs with the following goals:

- **Approximate Production Performance** – Although impossible to fully test production performance of final DSRC systems, moving the designs closer to likely designs would help better understand possible performance.
- **Realistic Protrusion** – Styling for experimental equipment is rarely a strong ingredient, yet it must be considered as a basic constraint for antenna designs.
- **Wide Flexibility** – At least one of two candidate designs must be usable on every make for every automotive manufacturer.
- **Easy Installation** – Although performance suffers with temporary mounting schemes, the prototype equipment must be used on multiple test vehicles for future testing and, therefore, must allow easy installation.
- **Involve Supply Base** – Engaging automotive suppliers early in development allows for wide understanding of technological hurdles and possibilities, and taps into vast engineering knowledge.
- **Answer Unknowns** – Several basic unknowns (e.g., desired polarization) needed answering to continue with standards development and future test kit designs.

1.1.1 Acceptable Performance

The term "acceptable performance" is unfortunately very application-specific and quite subjective; acceptable to one system or engineer might not be acceptable to another. Therefore, the Crash Avoidance Metrics Partnership Vehicle Safety Communications Consortium (CAMP-VSCC) brainstormed and investigated various safety systems and estimated the range of communications required for task effectiveness (see CAMP-VSCC Task 3 Report). For the OBU communications, the longest desired range was 1000m, but the system ("Approaching Emergency Vehicle Warning") would likely be permitted greater power allowances and, therefore, greater range than the typical OBU. The next greatest range was 500m ("Wrong Way Driver Warning"), and almost every other safety-related system needed 400m or less in range. Therefore, 400m was deemed the minimum acceptable system capability with 500m being a desired performance range given 100mW of power.

1.1.2 Statement of Work

The following document was written in conjunction with CAMP-VSCC by the identified contractor, M/A-COM, under a statement of work with the following activities:

- Activity 1: Define Target Antenna Performance
- Activity 2: Develop Candidate Antenna Designs
- Activity 3: Simulate Antenna Performance
- Activity 4: Prototype Reference DSRC Antennas
- Activity 5: Unit-Level Evaluation
- Activity 6: Vehicle-Level Evaluation
- Activity 7: Project Management
- Activity 8: Final Report

CAMP-VSCC chose a contractor to work on the program based upon antenna knowledge/experience, automotive knowledge/experience, quality of the facilities in regards to the Subproject's needs, proximity of facilities/personnel, cost, ability to meet the CAMP terms and conditions, and a subjective evaluation of the ease of program management.

As a result, the program succeeded in delivering all the identified deliverables and performance objectives with encouraging results regarding potential performance based upon a very conservative power budget. Two prototype antennas were simulated and built, and subsequently both designs were tested in the anechoic chamber, on the test range, and atop test vehicles. Field validation showed that the encouraging simulations and chamber results not only accurately predicted base performance, but also that true communication range exceeded expectations.

1.2 Definitions

The word "shall" will be used to state binding requirements of the component defined by this document. These requirements will be verified.

The word "must" will state requirements of other components or subsystems whose definitions are outside the scope of this document.

The word “will” is used to state either of the following:

a. Conditions that result from the immutable laws of physics.

b. Conditions that result from adherence to other stated binding requirements.

The word “withstand” will be defined as “Maintain design-intended functions and structural integrity while being subjected to the specified conditions.”

1.3 Applicable Documents

This section lists documents referenced as requirements for the component.

1.3.1 Government Documents

Suppliers are expected to be aware of and comply with worldwide component and vehicle standards and regulations where applicable. Requirements of national governments shall apply even if not explicitly stated below. Specific national requirements may be waived under specific purchase orders or engineering part drawings.

- FCC Report ET 98-7 Engineering & Technology Action – June 11, 1998
- FCC 02-302 NOTICE OF PROPOSED RULEMAKING AND ORDER Adopted: November 7, 2002 Released: November 15, 2002

1.3.2 CAMP – VSCC Documents

- Task 6 Antenna SOW - Vehicle Safety Communications Consortium: DSRC
- Antenna Basic Performance Understanding Statement of Work

1.3.3 Industry Documents

ASTM-E2213-02	Telecommunications and Information Exchange Between Roadside and Vehicle Systems — 5 GHz Band Dedicated Short Range Communications (DSRC) Medium Access Control (MAC) and Physical Layer (PHY) Specifications
IEEE 802.11a	Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications High-speed Physical Layer in the 5 GHz Band

1.4 Requirements

1.4.1 Component Definition

This section gives a high-level overview of the antenna assembly and defines its physical and electrical performance requirements.

1.4.1.1 Antenna Assembly

The antenna assembly will consist of the radiating element, a radome (housing), the mechanical mounting mechanism, a coaxial cable pigtail, and the SMA JACK connector.

1.4.1.2 System Operation

The antenna sub-system shall be capable of communicating with roadside units (RSUs) approximately 5m in height and other vehicles equipped with similar on-board units (OBUs). It is desired that the system will be capable of OBU-OBU and OBU-RSU communication at distances of up to 500m.

1.4.2 Environmental Requirements

1.4.2.1 Water Intrusion

The antenna shall be capable of withstanding typical outdoor exposure to rain, snow, and humidity without degradation of performance and/or mounting. The antenna, when properly installed to the vehicle, shall also provide a watertight seal to prevent leakage into the vehicle.

1.4.2.2 Temperature

The antenna shall be capable of withstanding typical vehicle interior and exterior temperatures. Specifically, the components in the antenna system shall meet the specifications when subjected to a temperature range of –40°C to +85°C (–40°F to +185°F).

1.4.2.3 Vibration

The antenna assembly shall be capable of withstanding typical vibrations as a result of normal shipping and handling and VSCC testing / demonstrations.

1.4.3 Electrical Requirements

Due to vehicle and mounting variations these requirements shall be met across the entire ITS-RS band (5.850-5.925GHz) as tested in an anechoic chamber.

1.4.3.1 5.9GHz Antenna Performance Requirements

1.4.3.1.1 Operating Frequency Range

The antenna shall meet all requirements across the entire ITS-RS band (5.850-5.925GHz) as defined by ASTM-E2213-02.

1.4.3.1.2 Impedance Match Requirement

The antenna shall have a VSWR equal to or better than 2:1 relative to 50 Ω measured at the antenna feed point. This specification is to be met across the entire ITS-RS band (5.850-5.925GHz) as defined by ASTM-E2213-02.

1.4.3.1.3 Free-Space Gain

The free-space gain of the antenna shall meet or exceed the following requirements measured at the antenna feed point. For antennas that require a ground plane, the free-space gain shall be measured with the antenna mounted at the center of a 1.0m rolled edge circular ground plane. If a diversity scheme is used the composite pattern of the individual antennas shall meet the same requirements.

Elevation Angle	Min Linear-Averaged Mean Gain	Polarization
0 (Horizon)	0dBil *	Vertical and RCP

* Assumes 100mW transmit power for OBU-OBU communications for distances up to 500m. This gain is necessary to support 3dB cable loss in the free-space link budget.

1.4.3.1.4 Vehicle Level Simulation

The expected antenna performance on a vehicle shall be simulated to demonstrate potential performance impacts due to vehicle structures. However, due to variation of vehicle/mirror types and software modeling limitations, no specific gain requirements will be identified. If actual vehicles cannot be modeled or does not provide additional benefit, the following guidelines should be met:

1. Models for roof-mounted antennas should assume that the antenna mounting location is free of roof racks, sunroofs, etc. relative to the signal wavelength. Based on this assumption, the vehicle roofs can be modeled as infinite ground-planes.
2. Sufficient side mirror material area should be included, in worst-case geometries, relative to the signal wavelength to ensure far field effects are captured.
3. If the mounting location is near other main body structures, relative to the signal wavelength, those structures should be included as necessary to ensure far field effects are captured.

1.4.3.1.5 Pattern Coverage

The antenna reception pattern shall provide sufficient coverage 360° in azimuth from 0° to 45° elevation. If sufficient coverage cannot be demonstrated with a single antenna strategy a diversity antenna strategy may be utilized. If a diversity scheme is used the composite pattern of the individual antennas shall meet the same requirements. Negative elevation angles are considered out of scope since most OBU communication will take place at near-zero relative elevation.

1.4.3.1.6 Polarization

The antenna design shall be capable of receiving either RHCP or vertical polarization. In the development of the candidate designs it would be preferred to have one of each design to demonstrate satisfactory performance with either polarization. The contractor shall provide supporting documentation regarding their selection of antenna polarization.

1.4.3.2 Electrical Interface Requirements

1.4.3.2.1 Coaxial Cable Electrical Properties

For antenna cable routing that is not subjected to repeated flexing and/or tight bend radii, the coaxial cable shall be RG-316 U with the following properties:

a) Nominal impedance shall be 50Ω.

b) Nominal capacitance shall be 29.0 pF/ft.

c) Attenuation shall be 0.394 dB/m at 200 Mhz and 0.951 dB/m at 1000 MHz.

d) DC ground resistance shall be 0.0279 Ω/m typical.

e) Center conductor D.C. resistance shall be 0.2759 Ω/m typical.

f) Isolation resistance between the center pin (conductor) and the shield shall be greater than $1x10^6$ Ω.

For antenna cable routing that has the potential to be subjected to repeated flexing and/or tight bend radii, the coaxial cable shall be Thermax 0.070" cable with the following properties:

a) Nominal impedance shall be 50 Ω.

b) Nominal capacitance shall be 29.0 pF/ft.

c) Attenuation shall be 0.46 dB/ft at 1575 MHz and 0.96 dB/ft at 5.90 GHz.

d) DC ground resistance shall be 0.0279 Ω/m typical.

e) Center conductor D.C. resistance shall be 0.2759 Ω/m typical.

f) Isolation resistance between the center pin (conductor) and the shield shall be greater than $1x10^6$ Ω.

If the cable routing is such that a lower loss cable is required, an inline connector can be used to transition between Thermax 0.070" or RG316 U and LMR195. The LMR195 cable should have the following properties: (reference www.timesmicrowave.com)

a) Nominal impedance shall be 50 Ω.

b) Nominal capacitance shall be 24.3 pF/ft.

c) Attenuation shall be 28 dB/ft at 5.80 GHz.

d) DC ground resistance shall be 4.9 Ω/1000ft typical.

e) Center conductor D.C. resistance shall be 7.58 Ω/1000ft typical.

f) Isolation resistance between the center pin (conductor) and the shield shall be greater than $1x10^6$ Ω.

1.4.3.2.2 Connector

The antenna coaxial cable pigtail shall be terminated with a SMA JACK connector, to be mated with the PC test kit.

The connector should be Tyco-Amp P/N 1051855-1 (SMA Straight Cable Jack, Crimp) or equivalent and must mate to Tyco-Amp P/N 1082034-1 (SMA Straight Cable Plug, Crimp) or equivalent.

1.4.4 Physical Requirement

1.4.4.1 Antenna Appearance

The final antenna appearance will be determined by mounting location and electrical design. The units to be delivered in Activity 4 do not require formal styling but should follow the guidelines detailed below. Potential styling options should be presented to the TMT during the development process and approved/documented during the weekly program review meetings. The final styling shall be aesthetically acceptable (to the VSCC) for internal and public research activities, tests, and demonstrations.

1.4.4.1.1 Finish

The visible portions of the antenna, when mounted to the vehicle, should have a smooth finish free of burrs, flashing, sink marks, blemishes, etc.

1.4.4.1.2 Color

The visible portions of the antenna, when mounted to the vehicle, should be black in color.

1.4.4.1.3 Shape

The shape of the visible portions of the antenna, when mounted to the vehicle, should be styled in order to minimize its overall size, visibility, and expected wind noise.

1.4.4.2 Mechanical

1.4.4.2.1 Mechanical Mounting

Designs shall be optimized for easy installation & removal, ruggedness, and versatility when mounting across a wide variety of vehicle types, makes, and models.

Side-View Mirror Assembly

The side-view mirror antenna assembly shall be capable of mounting to most vehicle side mirror housings. The mounting mechanism should be designed to accommodate as wide a range of vehicle types as possible. The design should be a snap-fit or clamp-type attachment with the following design goals:

- Capable of withstanding wind forces due to vehicle travel at up to 100mph.
- Tool-free installation & assembly.
- No damage to mirror housing as a result of installation/removal.

Roof Mounted Assembly

The roof mounted antenna assembly shall be capable of mounting to all sheet metal vehicle roofs. The mounting mechanism should be designed to accommodate as wide a range of vehicle roof curvatures/profiles as possible and should not require a hole in the roof for cable routing. The design should be a magnetic base attachment with the following design goals:

- Capable of withstanding wind forces due to vehicle travel at up to 100mph.
- Tool-free installation and assembly.
- No damage to vehicle roof as a result of installation/removal.

1.4.4.3 Label Requirements

The visible portion of the antenna, when mounted to a vehicle, shall be free of any markings, logos, company names, etc. The antenna shall be clearly marked with a label attached to the pigtail that includes a part number and serial number (e.g. 001 through 040). If a diversity scheme is implemented that requires antenna pairs the label should include identification markings to signify front/back or left/right (e.g. 001R and 001L).

1.4.5 Antenna Correlation Matrix

The Antenna Correlation Matrix will trace all factors, developed/recognized constraints or enablers directly to originating requirements from the VSCC TMT and applicable documents identified in section 2. The matrix will also identify the level of testing required to show compliance with each requirement and when the results of such testing were approved.

1.4.5.1 Antenna Correlation Matrix Terminology

This paragraph defines the acronyms, abbreviations, and special terms used in this section.

Validation Method:	Level:
A = Analysis	V = Vehicle

D = Demonstration	C = Component (Anechoic Chamber)

I = Inspection

T = Test

1.4.5.2 Antenna Correlation Matrix

Requirement		Source			Validation	
Paragraph	Description	Document/Meeting	Paragraph	Date	Method	Test Report/Date
3.2.1	Water Intrusion	SOW	ACTIVITY 2	02JUL03	C/T	
3.2.2	Temperature	ASTM-E2213-02	8.8.6	10JUN02	C/T	
3.2.3	Vibration	SOW	ACTIVITY 2	02JUL03	C/T	
3.3.1.1	Operating Frequency Range	ASTM-E2213-02	8.8.3.1	10JUN02	C/T	
3.3.1.2	Impedance Match	N/A	N/A	30OCT03	C/T	
3.3.1.3	Free Space Gain	N/A	N/A	30OCT03	C/T	
3.3.1.4	Vehicle Level Simulation	TELECON	N/A	03NOV03	C/A	
3.3.1.5	Pattern Coverage	KICKOFF	N/A	26SEP03	C/T	
3.3.1.6	Polarization	SOW	ACTIVITY 2	02JUL03	C/T	
3.3.2.1	Coaxial Cable Electrical Properties	N/A	N/A	30OCT03	C/A	
3.3.2.2	Connector	KICKOFF	N/A	26SEP03	C/I	
3.4.1	Antenna Appearance	SOW	ACTIVITY 2	02JUL03	C/I	
3.4.2.1.1	Antenna Assembly Mounting Side-view Mirror Assembly	TELECON	N/A	27OCT03	C/I	
3.4.2.1.2	Antenna Assembly Mounting Roof Mounted Assembly	TELECON	N/A	27OCT03	C/I	
3.4.3	Label requirements	TELECON	N/A	06OCT03	C/I	

1.5 Selection of Antenna Polarization

The Task 6 Antenna SOW requires both vertical and circular polarization antenna design. M/A-COM strongly recommends the adoption of vertical polarization only for the following reasons:

1. Vehicle sheet metal will serve as the ground plane and will degrade reception of horizontally polarized waves at or near the horizon.

Figure 1 is a simple diagram of a free space – perfect conductor interface. By utilizing the Kirchoff's voltage law around the boundary *abcd* and the fact that E=0 everywhere inside the conductor you can determine one of the basic boundary conditions for electromagnetic fields, that the tangential component of the E field on a conductor surface is zero (E_t=0).

$$\text{As } \Delta h \rightarrow 0$$

$$\oint_{abcd} E \cdot dl = E_t \Delta w = 0$$

$$E_t = 0$$

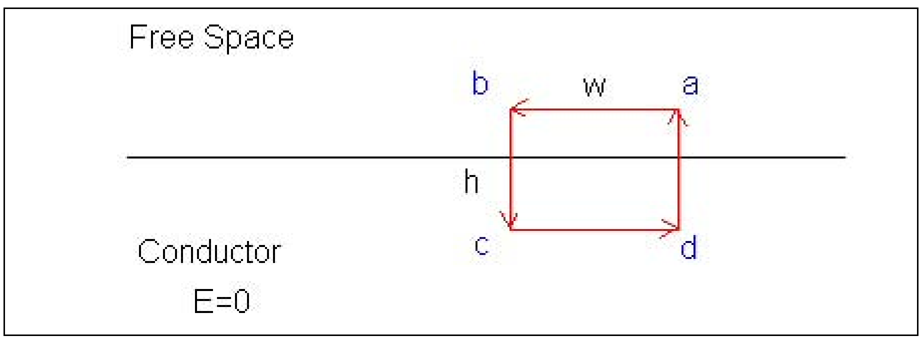


Figure 1-A. Free Space – Conductor Interface

To further illustrate this condition, M/A-COM has provided pattern data of a circular polarized antenna on a ground plane receiving rotating linear signals over different elevation angles (Figure 2). The source antenna is a vertically polarized antenna that is rotating to create right hand circular polarized waves. At boresight the ground plane does not impact the antenna reception and the pattern shows high circular polarization purity and low axial ratio. At the horizon, you can see the effects of the ground plane negating the horizontal component of the rotating linear transmission antenna. The lower elevations have a high axial ratio with the maximum coming from the vertical polarization and the deep nulls resulting from the horizontal polarization.

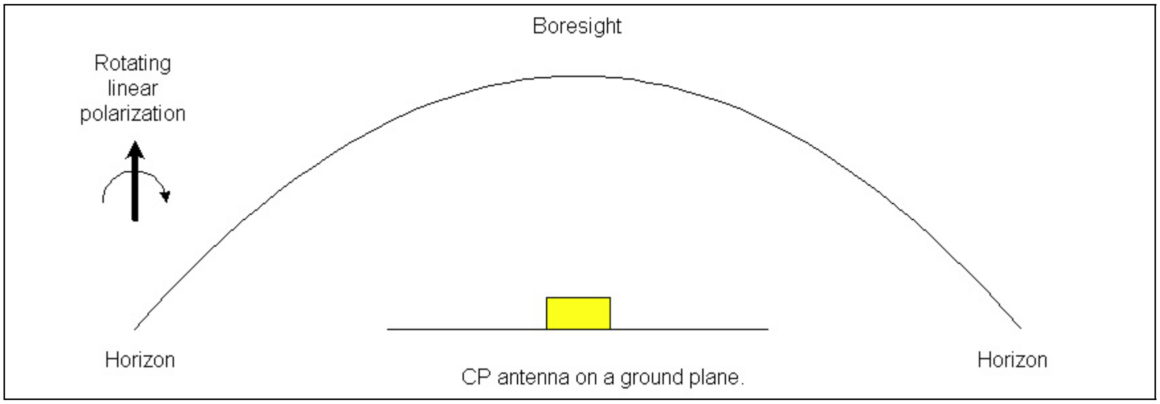


Figure 1-B. Test Setup for CP Antenna

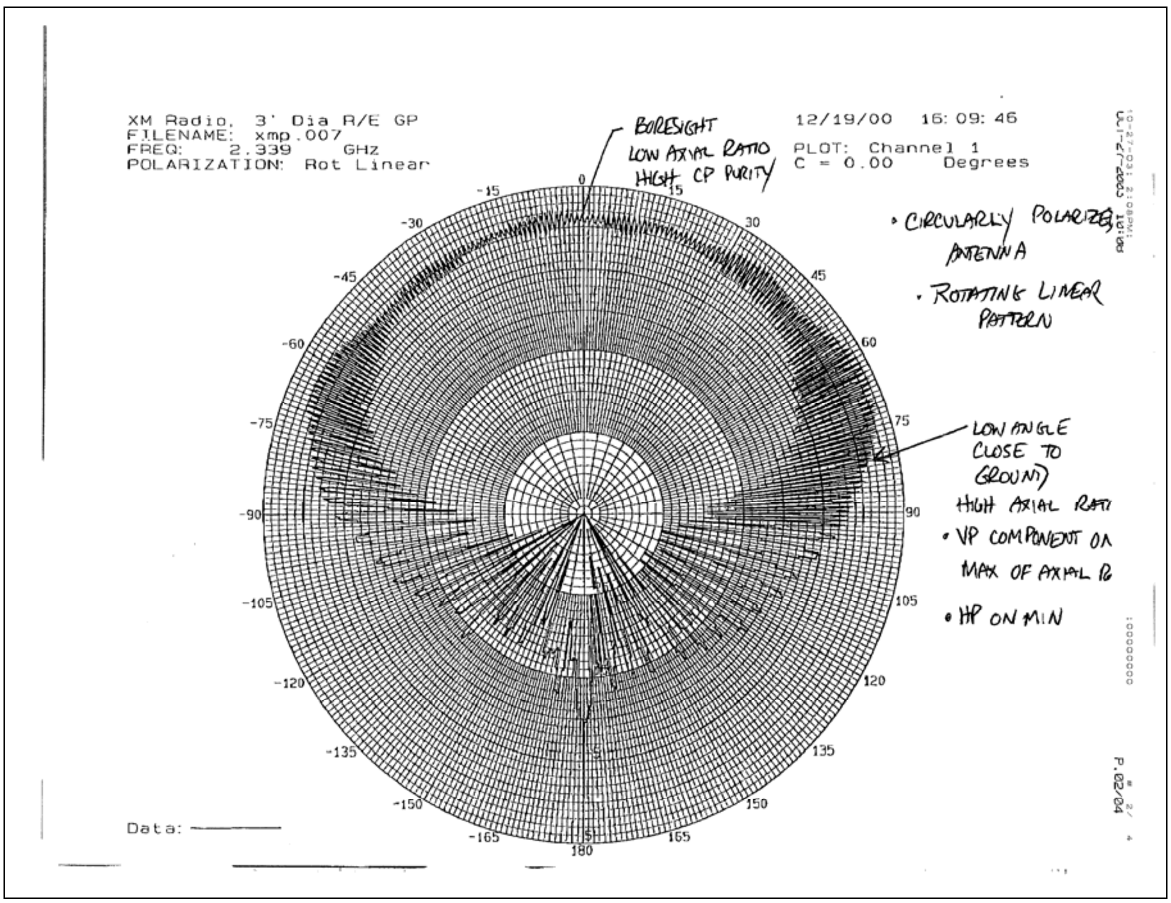


Figure 1-C. CP Antenna Reception on a Ground Plane

2. System complexity would be increased due to CP antenna limitations and pattern coverage requirements.

Initial analysis has shown that at least four antennas would be required to provide sufficient omni-directional coverage with acceptable axial ratio across the required elevation angles. The current receiver has diversity capability for two antennas. It is expected that the added cost of additional components and modification of the receiver to accommodate four antennas would significantly increase the overall subsystem cost. Additionally, this type of solution would not eliminate the issues described in item 1.

1.6 Thermax 0.070” Cable Test Data

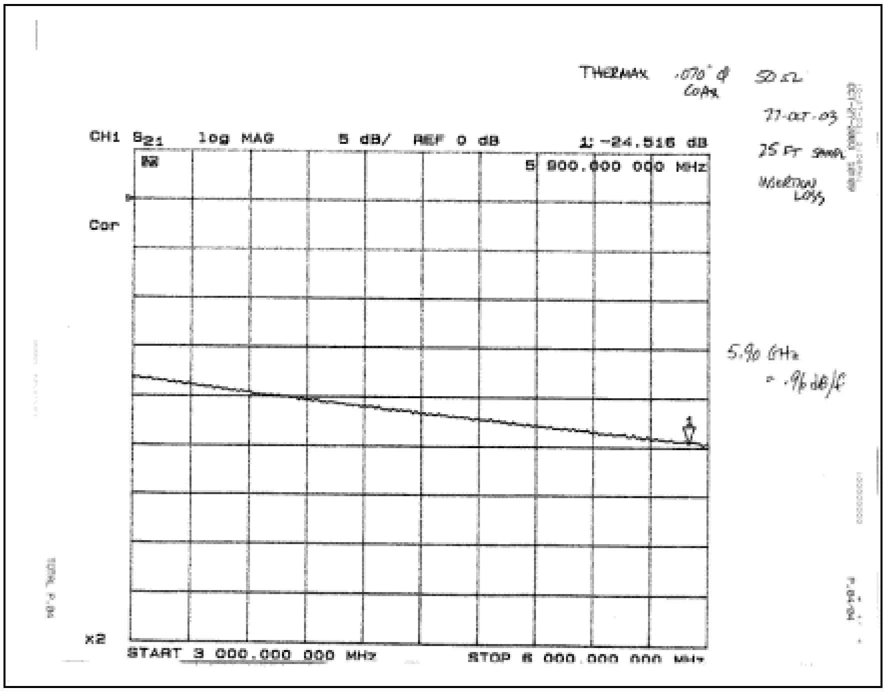


Figure 1-D. Swept Gain of a 25 ft Long Sample From 3GHz to 6GHz.

2 Antenna Subproject Simulation Results

2.1 Candidate Antenna Design Description

M/A-COM has developed two potential antenna designs, a magnetic mounted roof application and a diversity solution for a clamp-type side-view mirror application.

Roof mounted antenna design description:

- 5/8-wavelength monopole (internal element is approximately 1” tall).
- Requires approximately 2” radius of uninterrupted sheet metal surrounding the mounting location to serve as the ground plane.
- Overall omni-directional pattern at the required elevation angles.
- Geloy plastic radome (housing).
- Magnetic mounting mechanism with a coaxial pigtail parallel to the roof line.

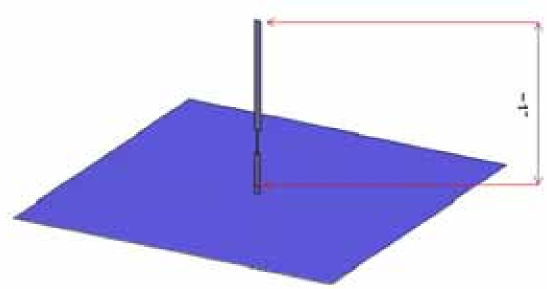


Figure 2-A. Initial Antenna Element Design Over a Ground Plane

Side mirror mounted antenna design description:

- Two-element dipole array.
- Ground plane independent
- Individual antennas will provide cardiod pattern coverage.
- Geloy plastic radome (housing).
- Clamp-type mounting mechanism with bottom exit coaxial pigtails.

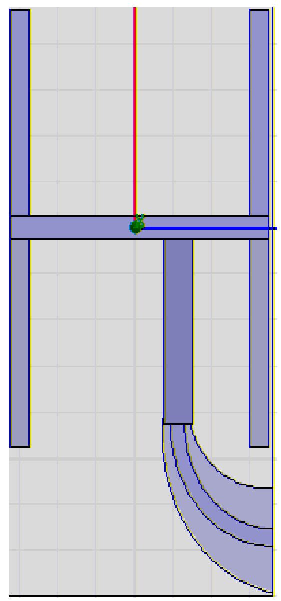


Figure 2-B. 2D View of Dipole Array

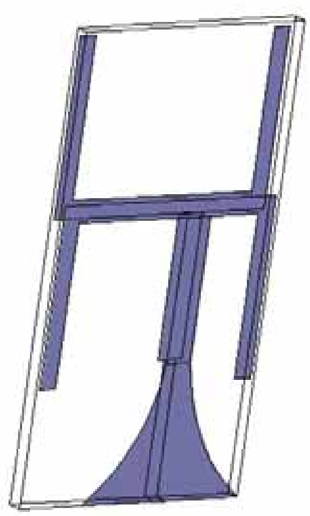


Figure 2-C. Isometric View of Dipole Array

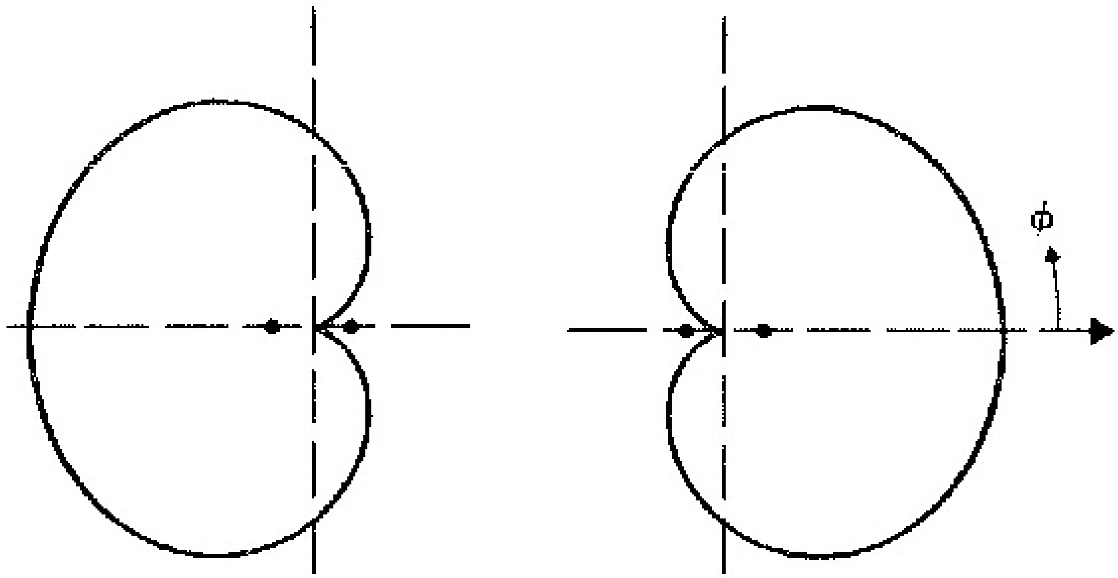


Figure 2-D. Theoretical Cardiod Patterns for Each Dipole Array (Driver/Passenger Side)

2.2 Antenna Design Overview

M/A-COM has developed two potential antenna designs to meet the Antenna Subproject Specification (Revision 1.1 11/5/03): a magnetic mounted roof application and a diversity solution for a clamp-type side-view mirror application. Due to the limitations and complexity of systems that incorporate circular polarized antennas both of these designs will be vertically polarized.

2.3 Software Overview

M/A-COM is currently using HFSS V9.0 and Designer V1.1 from Ansoft Corp to simulate antenna design performance. HFSS is capable of performing finite element method (FEM) through automatic adaptive mesh generation and refinement, tangential vector finite elements, and Adaptive Lanczos Pade Sweep (ALPS). HFSS automatically computes multiple adaptive solutions until a user-defined convergence criterion is met. Field solutions calculated from first principles accurately predict all high-frequency behavior such as dispersion, mode conversion, and losses due to materials and radiation. Some of the key product capabilities that we will be incorporating in this simulation are (reference www.ansoft.com):

Powerful Drawing Capabilities
Features of the 100% AutoCAD-compatible, fully integrated ACIS solid modeler include:

Advanced Materials
The comprehensive materials database contains permittivity, permeability, electric, and magnetic loss tangents for common substances.

Powerful Features for Antenna Design
Calculate antenna metrics such as gain, directivity, far-field pattern cuts, far-field 3D plots, and 3dB beamwidth. Plot polarization behavior including spherical field components, circular polarization field components, Ludwig's third definition field components, and axial ratio. Model half, quarter, or octet symmetry and automatically calculate far-field patterns.

Wideband Fast Frequency Sweep
A new fast frequency sweep technology called Adaptive Lanczos Pade Sweep (ALPS) has been implemented for efficient broad-band simulation. ALPS can produce a reduced order model for the structure that is valid over a broad frequency range by computing the system poles and zeros. ALPS includes port dispersion to determine input power level versus frequency and out-of-band rolloff accurately.

2.4 Design Specifications

In free space, the model simulation should meet the following requirements (Reference Antenna Subproject Specification Rev 1.1 11/5/03):

VSWR equal to or better than 2:1 relative to 50 Ω (at the antenna feed point)

Elevation Angle	Min Linear-Averaged Mean Gain	Polarization
0 (Horizon)	0dBil *	Vertical and RCP

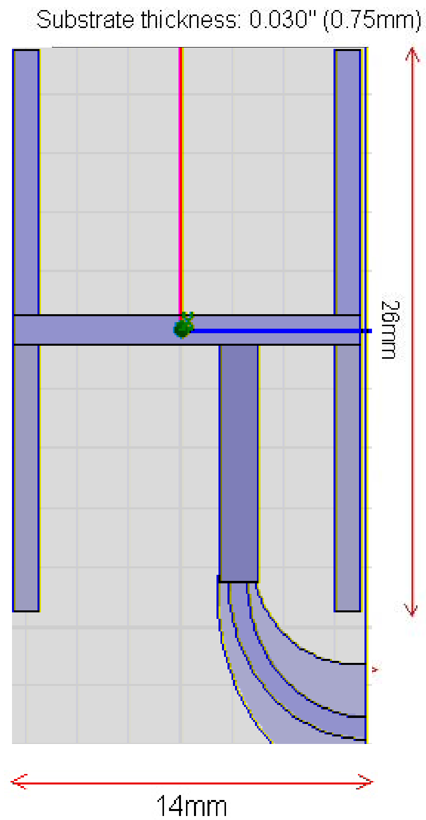
2.5 Side-View Mirror Simulation

2.5.1 Design Description

Side mirror mounted antenna design description:

- Two-element dipole array.
- Ground plane independent.
- Individual antennas will provide cardiod pattern coverage.
- Geloy plastic radome (housing).
- Clamp-type mounting mechanism with bottom exit coaxial pigtails.

2.5.2 Dimensioned Layout



2.5.3 Model Assumptions

The HFSS model assumed that the mirror housing and antenna radome would both be manufactured using the GE plastic Geloy. In order to determine the effects of the mirror and mirror housing both free-space and mirror-mounted models were simulated. The side-view mirror model assumed typical industry dimensions and materials. The results of these simulations have shown that very little energy would be transmitted in the direction of the vehicle. The combination of the distance to the A-pillar compared to the signal wavelength and the shape of the pattern support the assumption that the A-pillar would not have an affect on the pattern and therefore was not incorporated into the model.

2.5.4 VSWR/Impedance

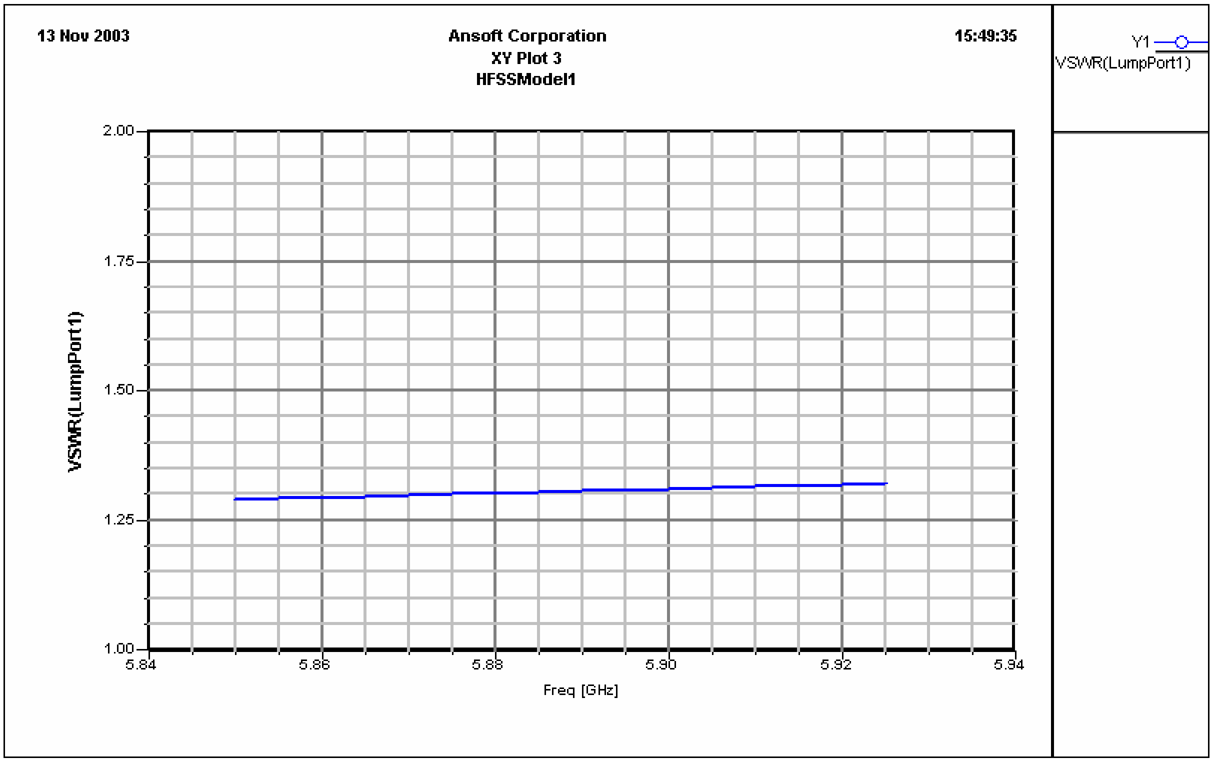


Figure 2-E. VSWR – Free-Space Dipole Array

The free-space swept VSWR models demonstrates that there is a sufficient margin to the 2:1 VSWR requirement. The VSWR is relative constant at ~1.3:1 across the entire frequency band 5.850GHz to 5.925GHz.*

** Note: Measuring VSWR at the antenna feed point is a conservative assumption. The added signal loss due to the coaxial cable pigtail will improve the VSWR as seen by the receiver.*

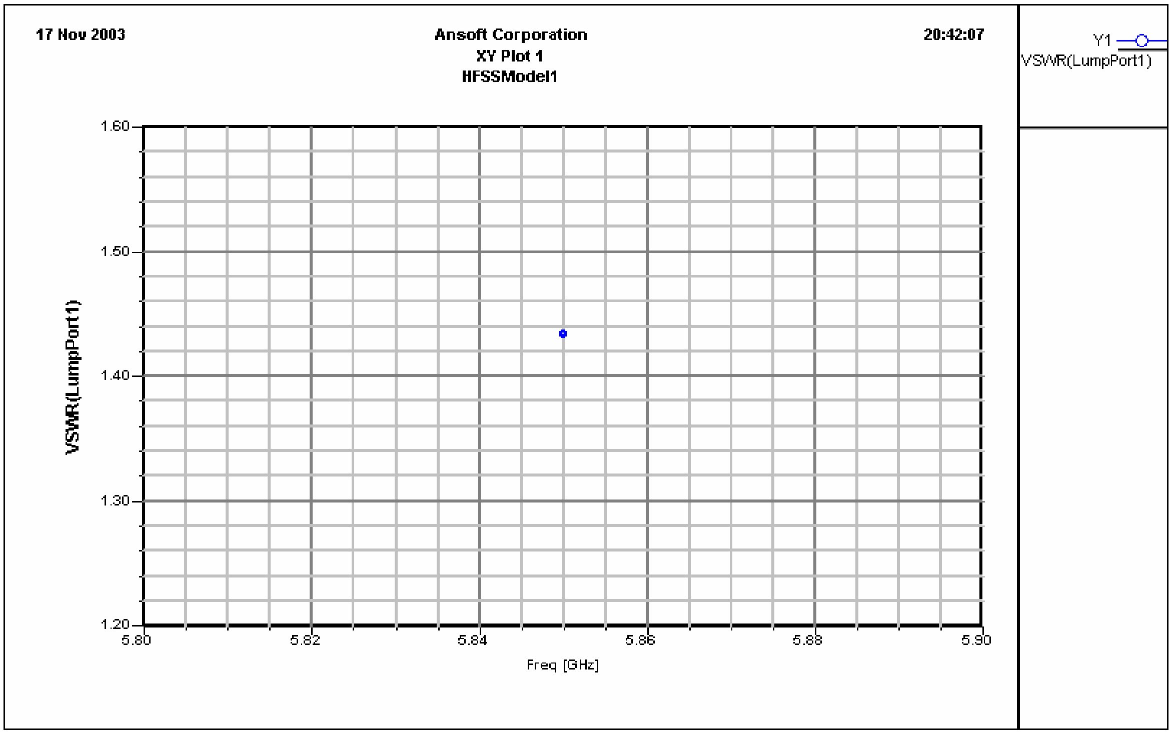


Figure 2-F. VSWR – Dipole Array on Side-View Mirror @ 5.850GHz

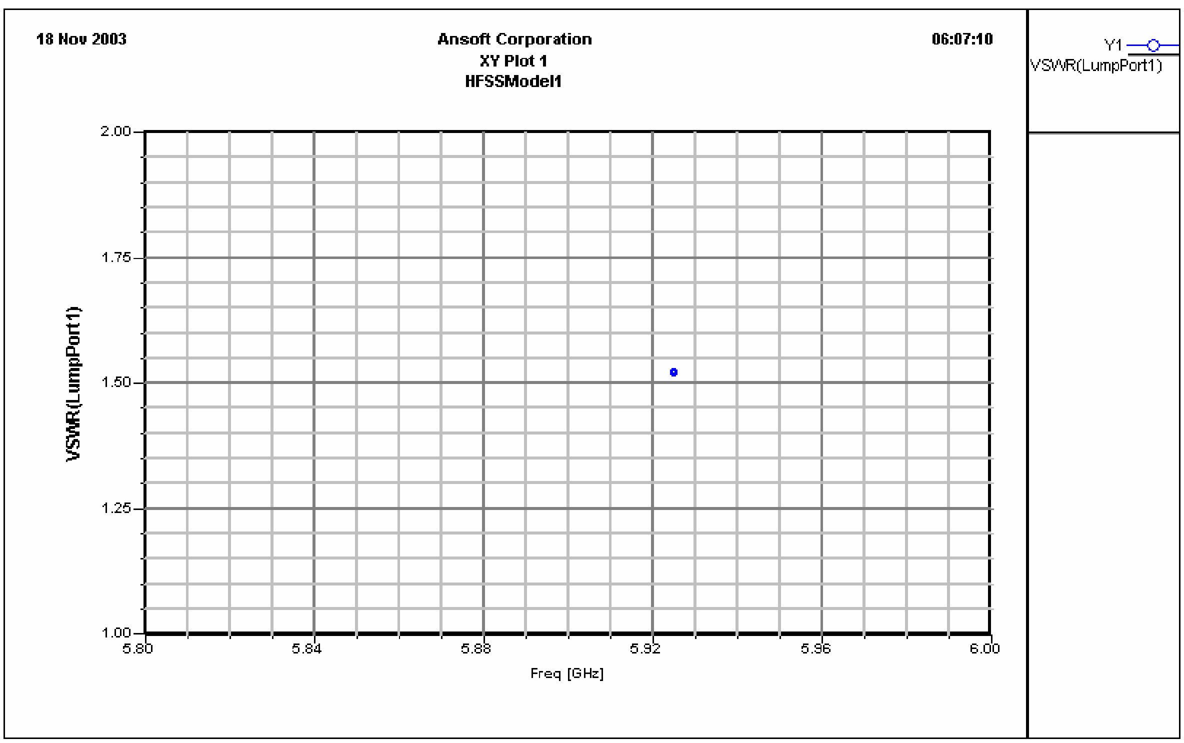
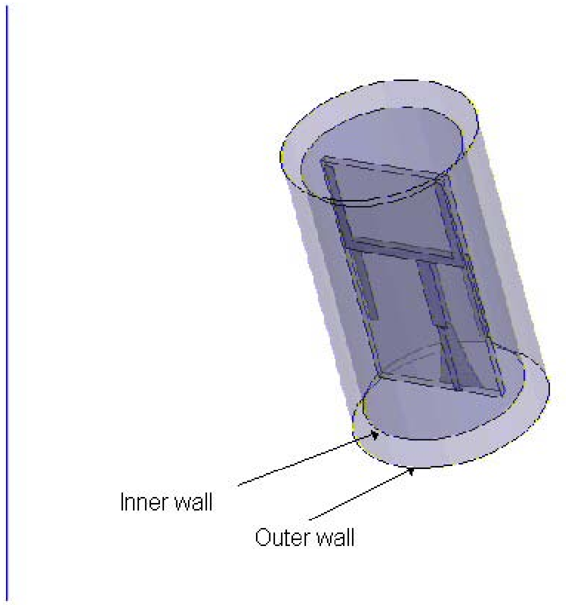


Figure 2-G. VSWR – Dipole Array on Side-View Mirror @ 5.925GHz

The VSWR model was also run with the typical side view mirror model. The side-view mirror structure did not have a significant impact on the input impedance of the antenna. Due to the size of the model and software limitations a mid-band VSWR measurement was taken: ~1.45:1 @ 5.9GHz.

2.5.5 Free-Space Pattern/Gain Plots (Bottom Feed-Point)

Gain plots and pattern measurements were simulated with the antenna element in free space encased in a generic cylindrical Geloy radome. The results show a 3-4dB margin to the 0dBi requirement from 0° (front) to 180° (rear) on one side of the vehicle. The peak gain of ~4.7dB is between 150° and 180°.



Isometric view - Antenna element in transparent Geloy radome.

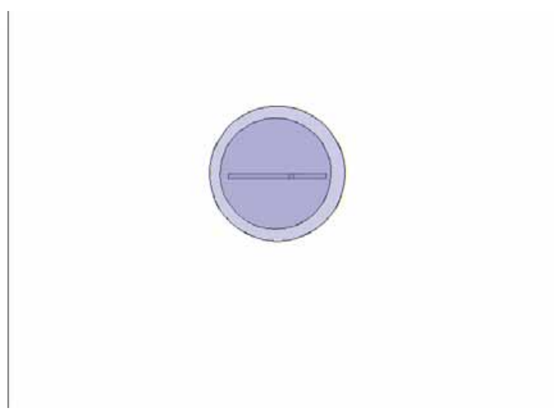


Figure 2-H. Side and Top Views

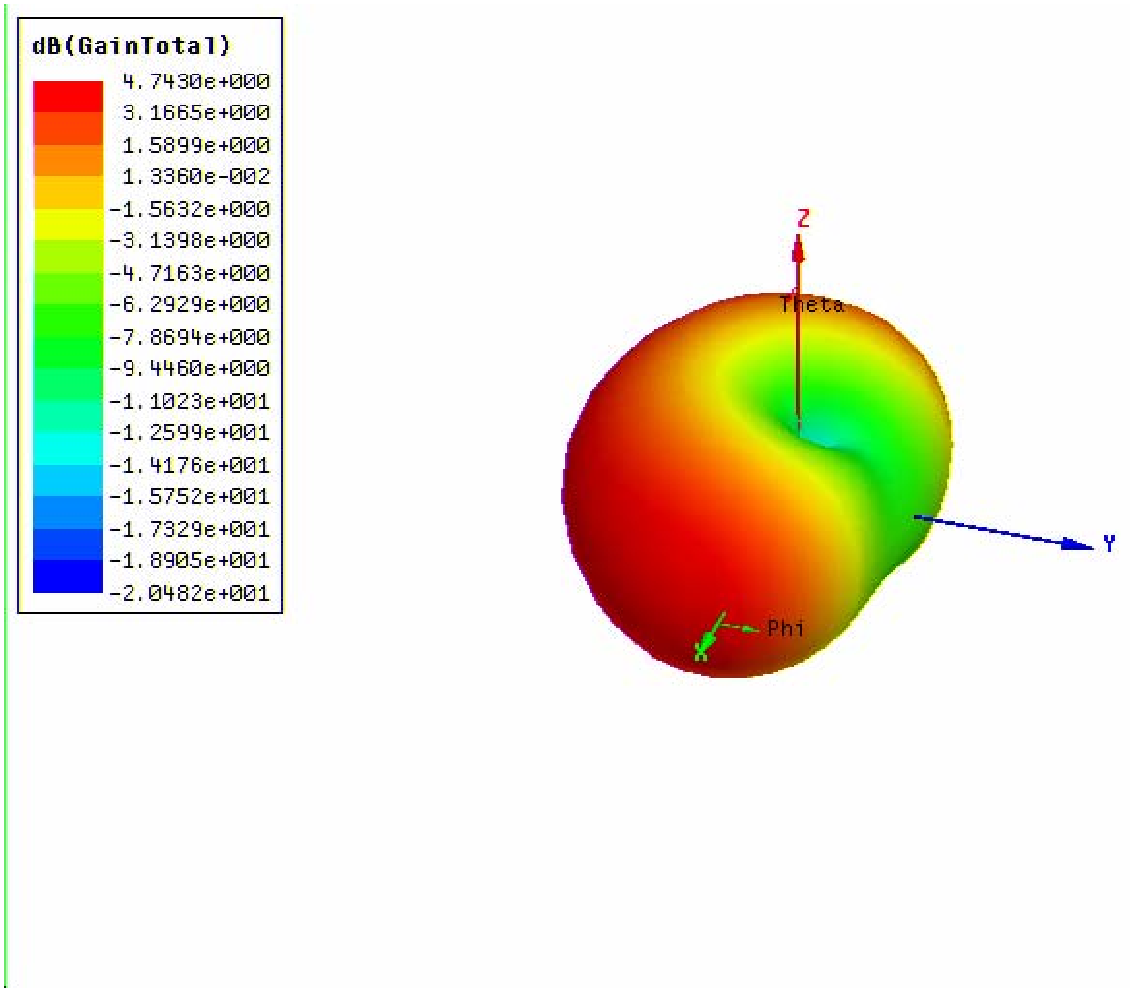


Figure 2-I. Isometric View – Dipole Array in Free Space (Bottom Feed-Point)

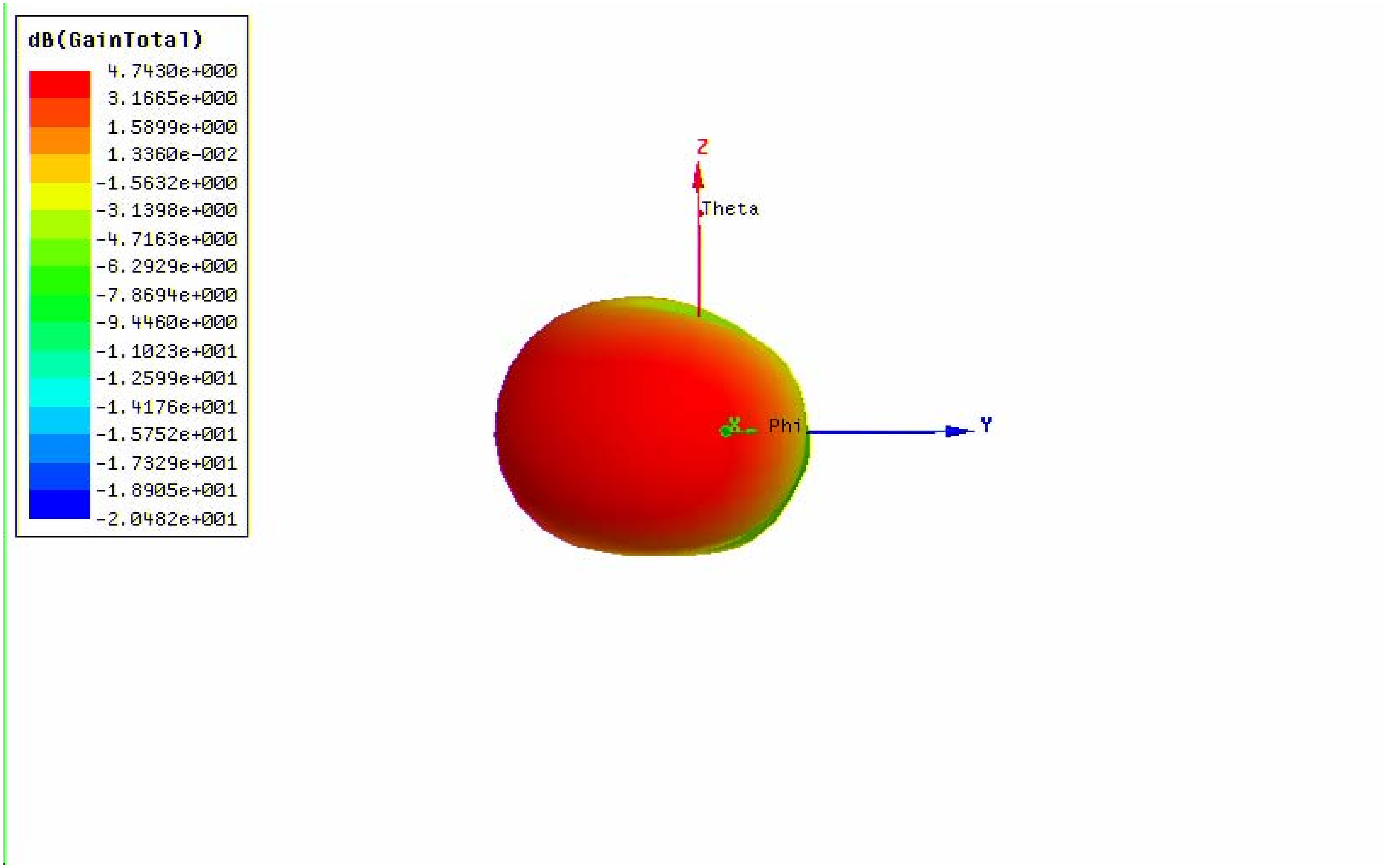


Figure 2-J. Side View– Dipole Array in Free Space (Bottom Feed-Point)

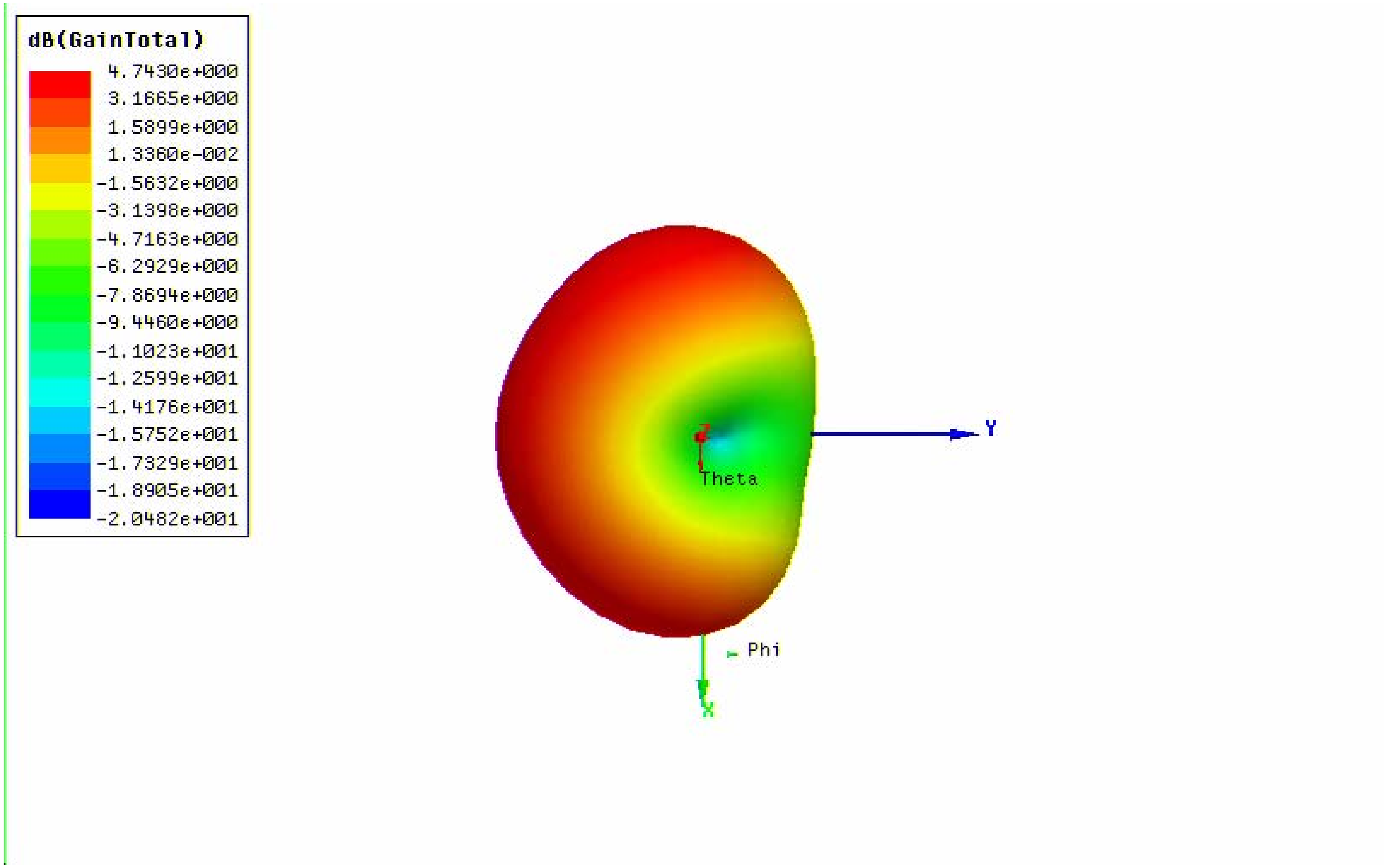


Figure 2-K. Top View– Dipole Array in Free Space (Bottom Feed-Point)

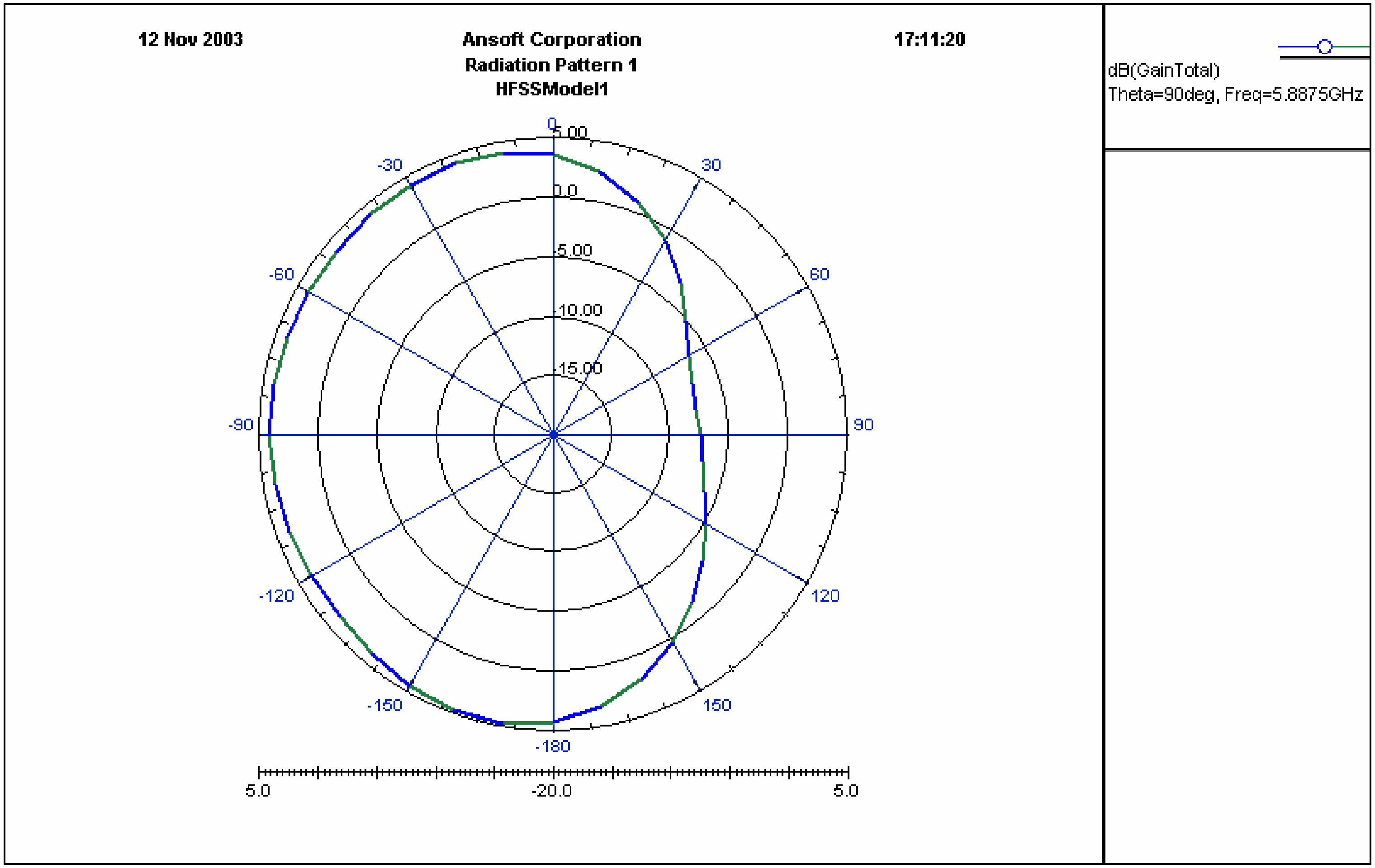
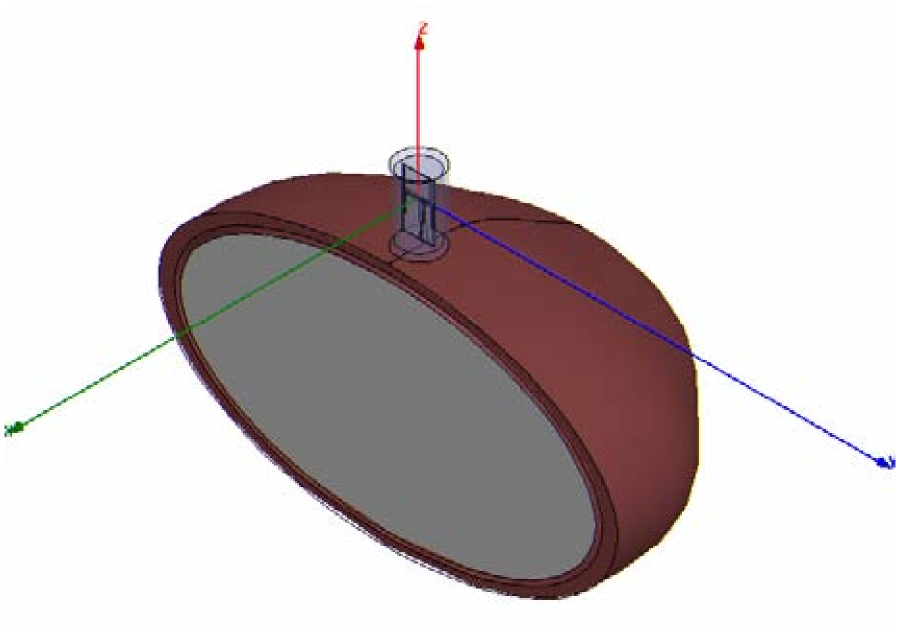
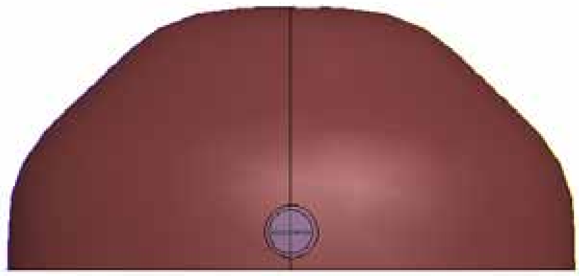


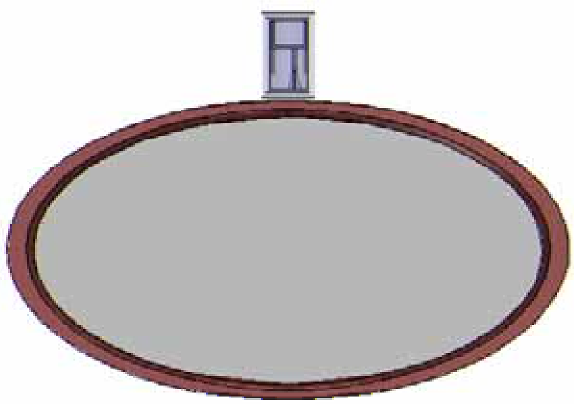
Figure 2-L. Radiation Pattern – Dipole Array in Free Space 0° Elevation (Bottom Feed-Point)

2.5.6 On-Mirror Pattern/Gain Plots

Gain plots and pattern measurements were then simulated with the antenna element in a generic cylindrical Geloy radome mounted on a typical side view mirror housing. The results show a perturbation of the pattern and a drop in gain towards the front and rear of the vehicle. The model still indicates satisfactory gain 0° (front) to 180° (rear) on one side of the vehicle. The peak gain of ~4.3dB is between 60° and 120°.







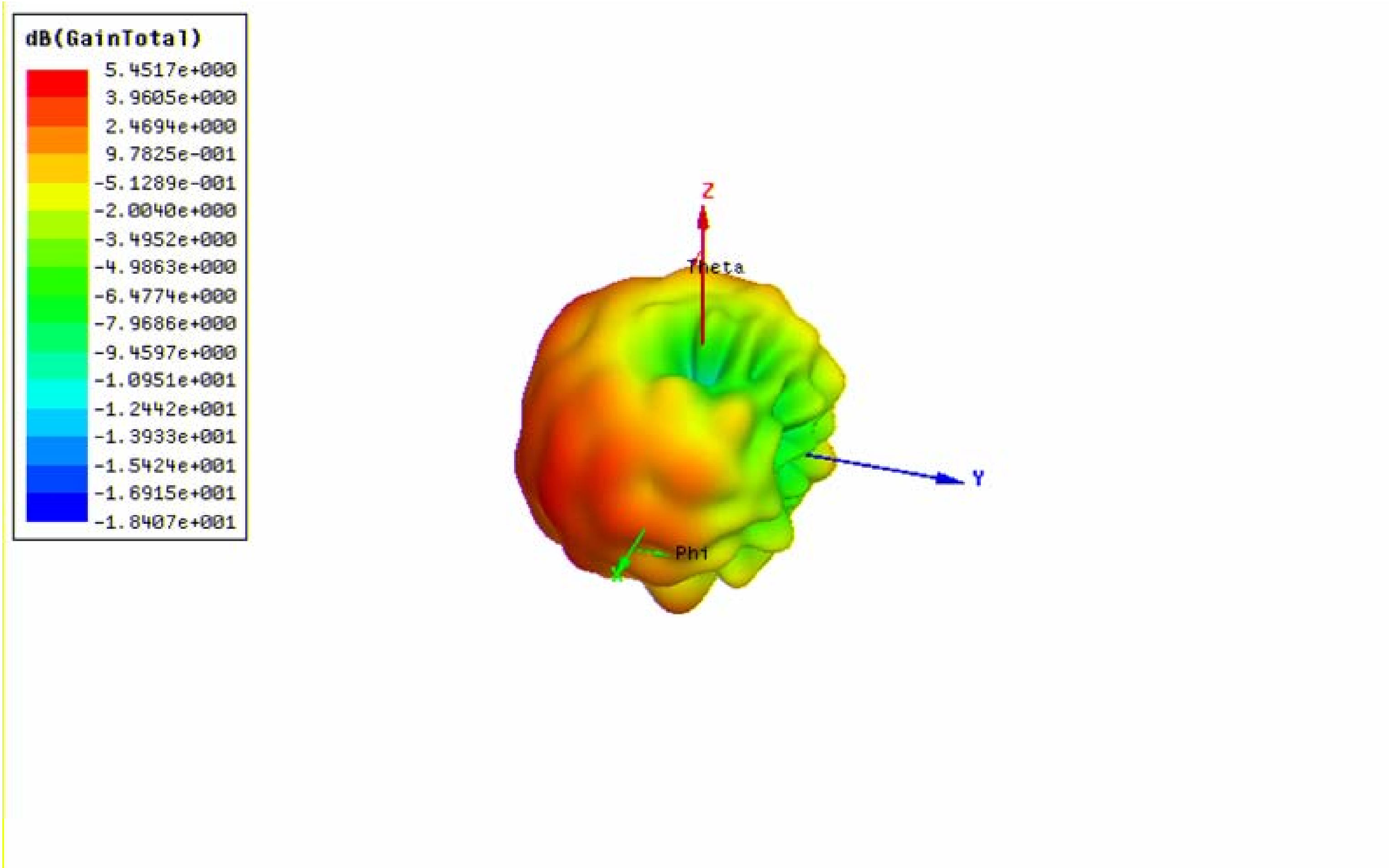


Figure 2-M. Isometric View – Dipole Array on Side-View Mirror

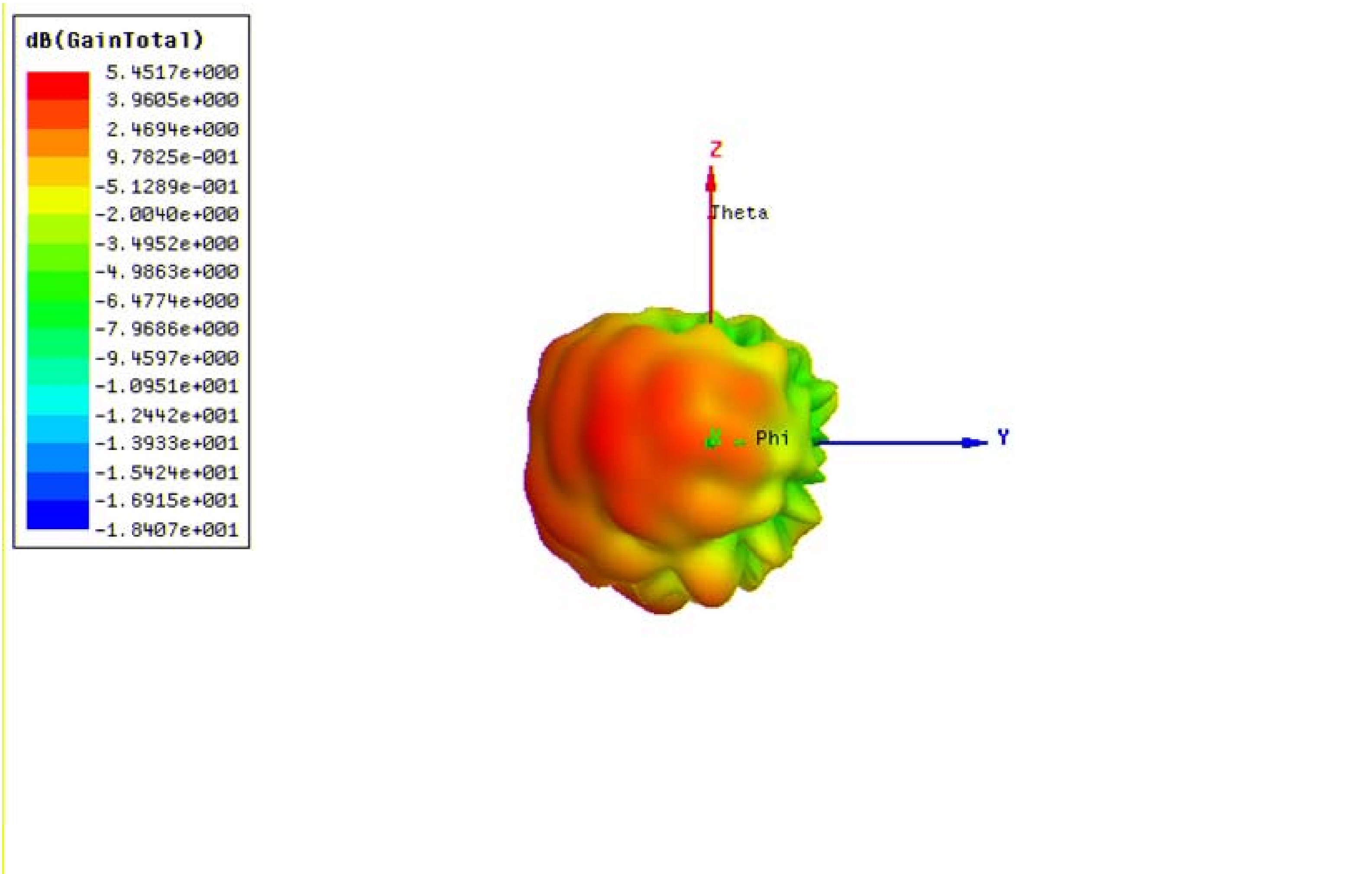


Figure 2-N. Top View – Dipole Array on Side-View Mirror

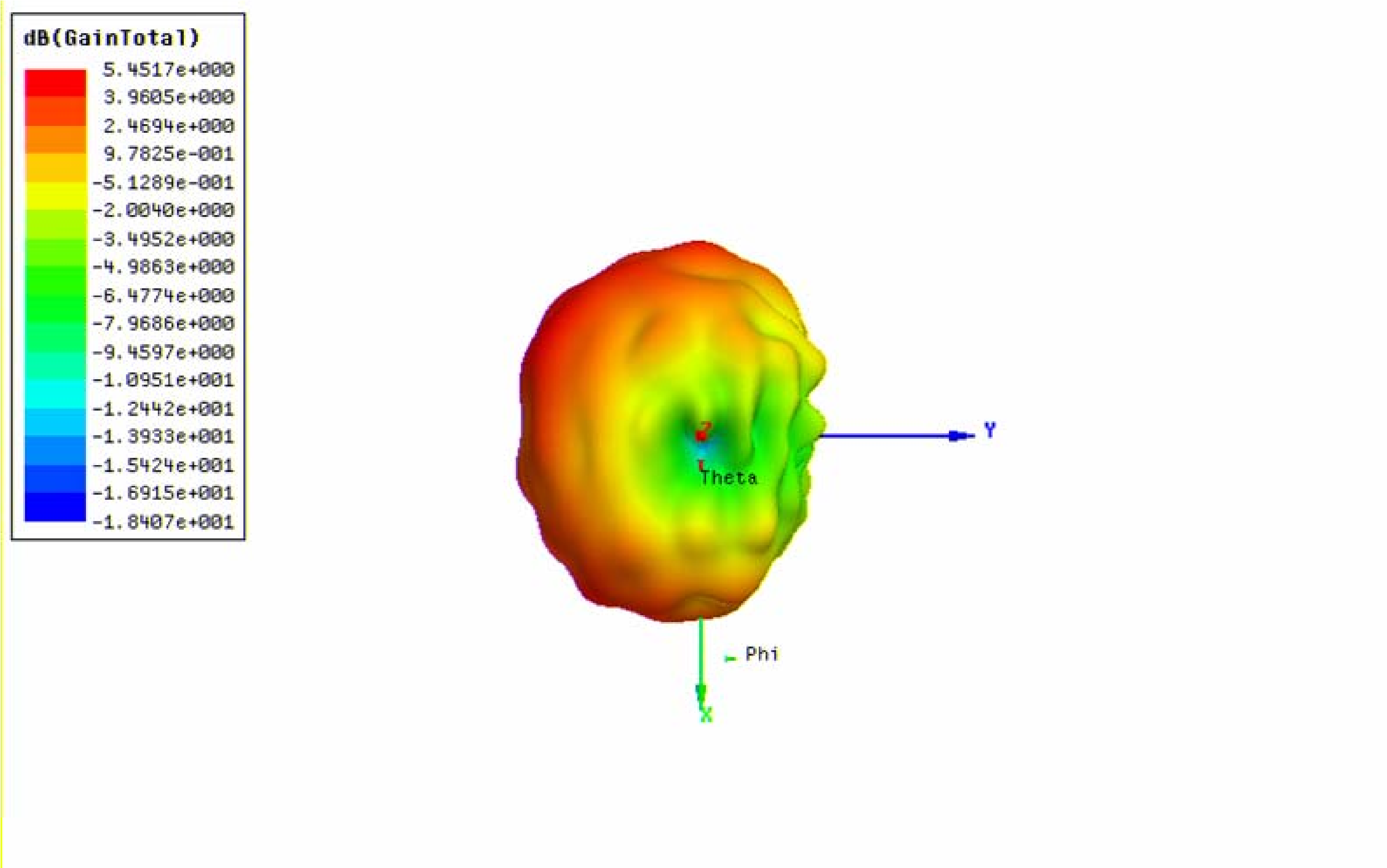


Figure 2-O. Side View – Dipole Array on Side-View Mirror

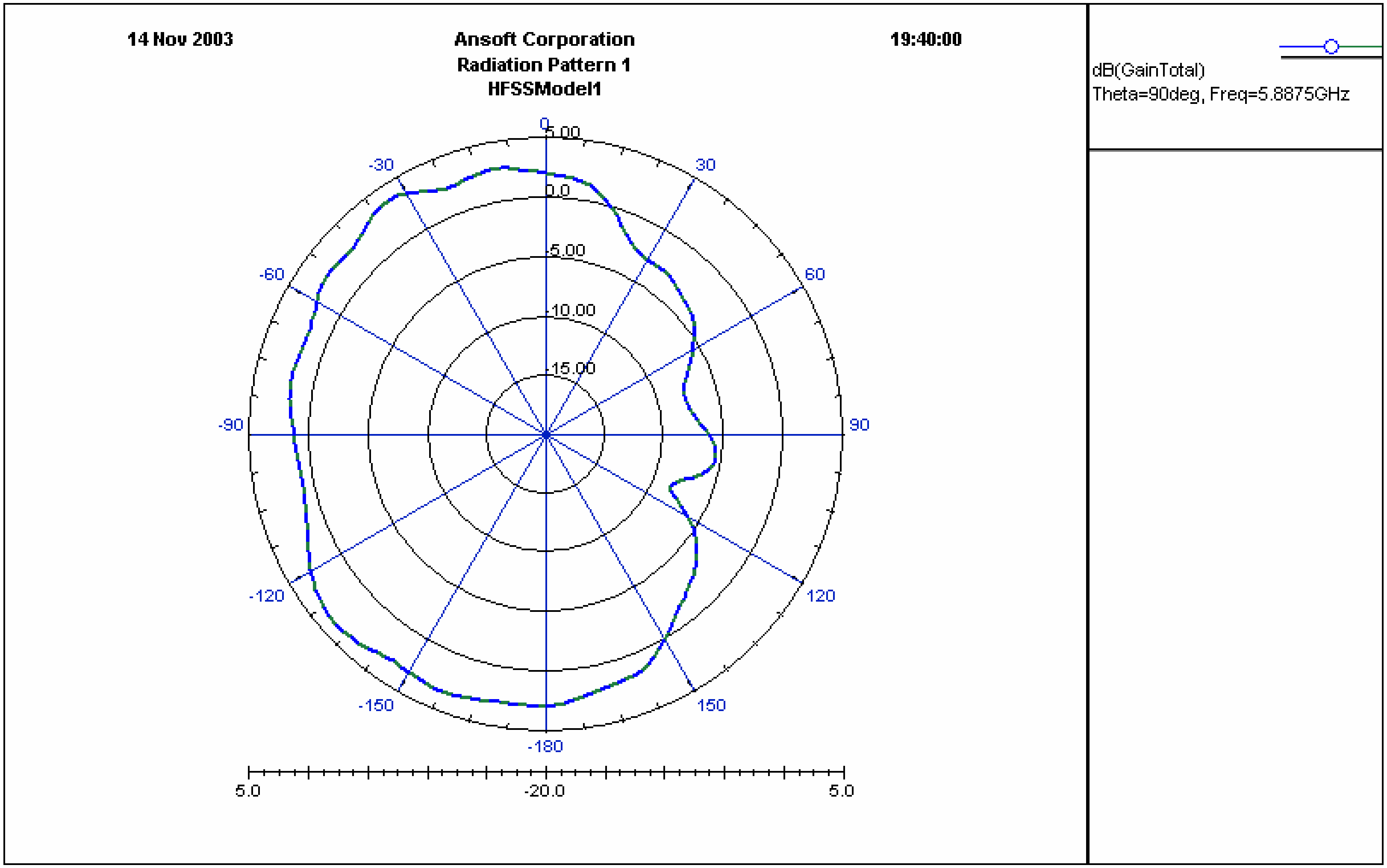
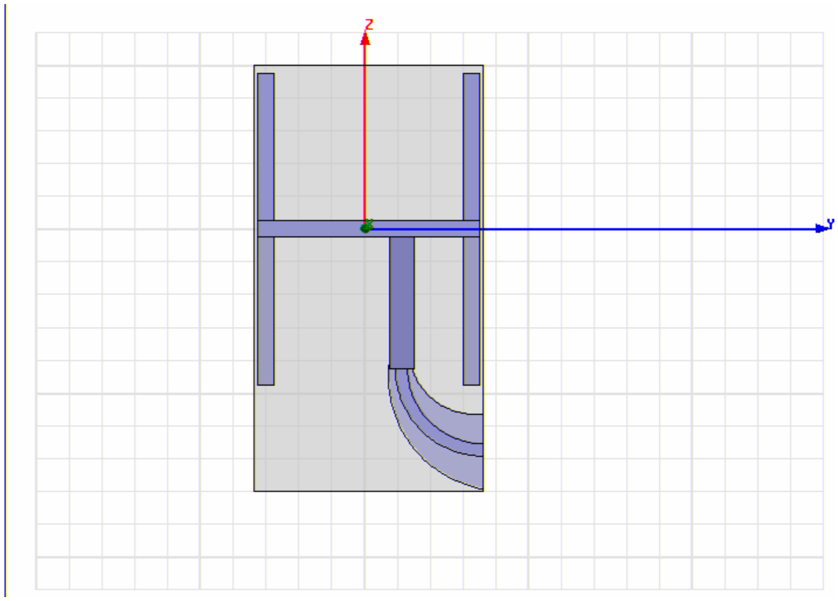


Figure 2-P. Radiation Pattern – Dipole Array on Side-View Mirror 0° Elevation

2.5.7 Free-Space Pattern/Gain Plots (Side Feed-Point)

To provide added flexibility for the mounting designs a second antenna element design was developed with a side feed-point. This simulation did not show any significant differences between the bottom and side feed-point designs.



Dipole Array -

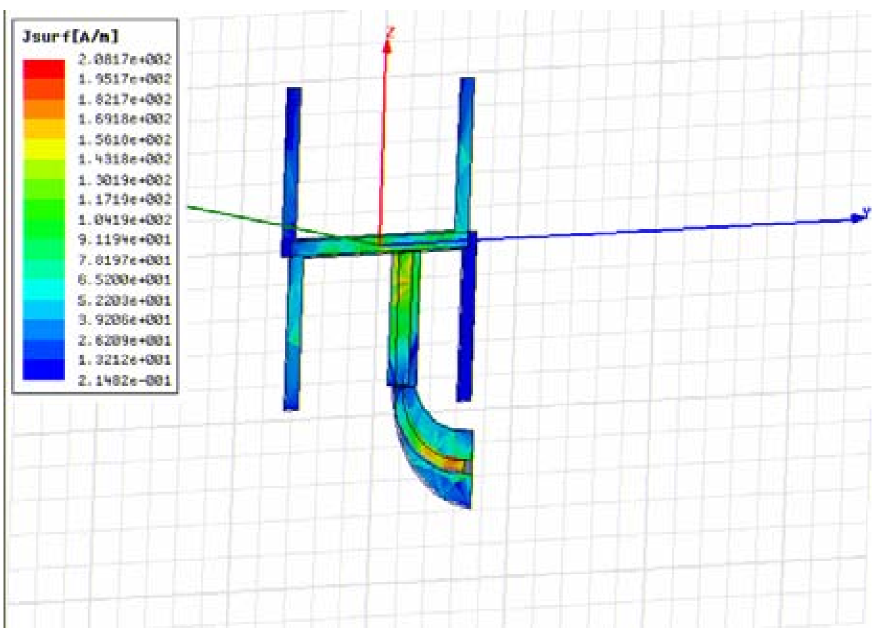


Figure 2-Q. Dipole Array – Current Distribution

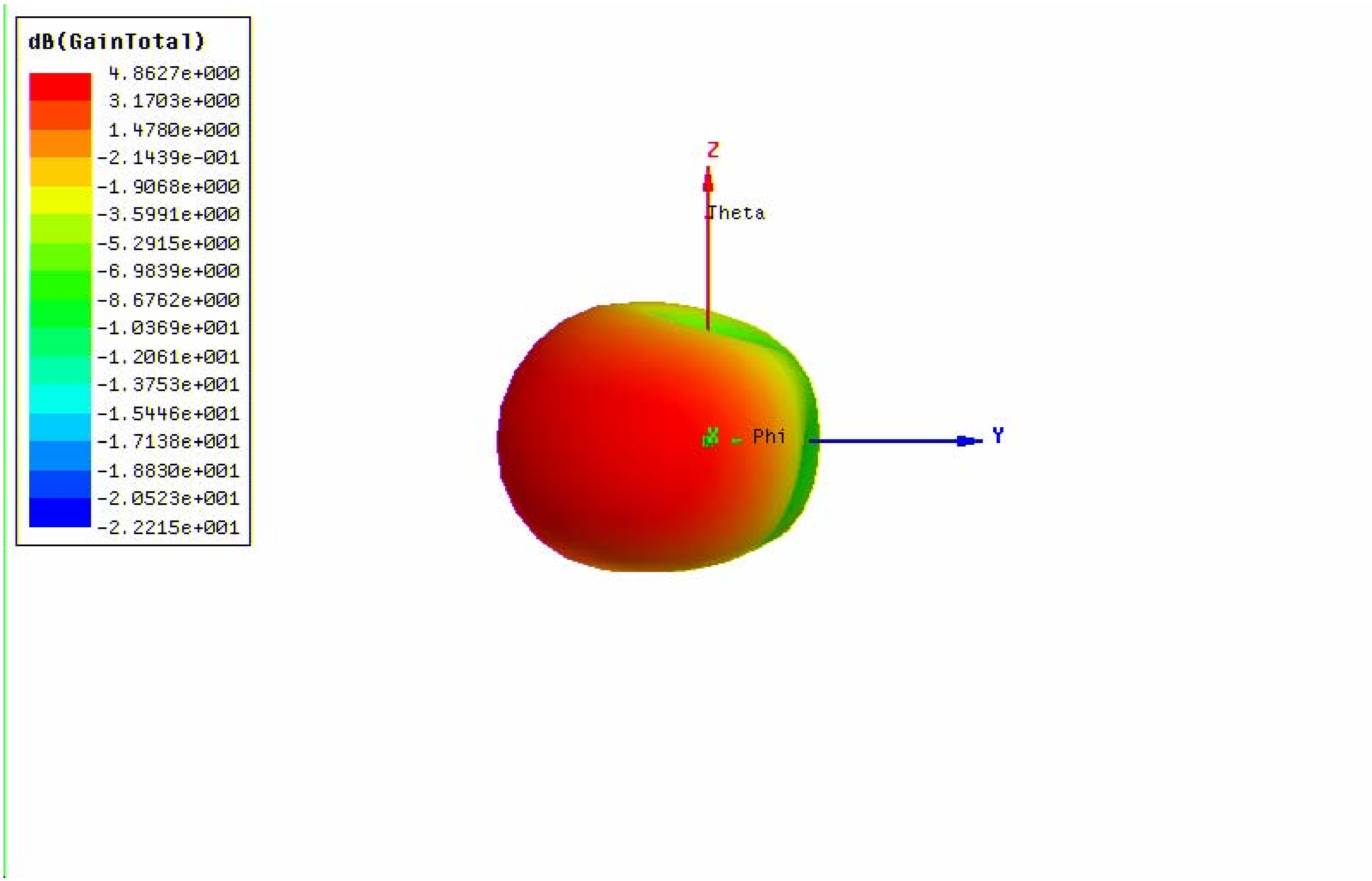


Figure 2-R. Side View– Dipole Array in Free Space (Side Feed-Point)

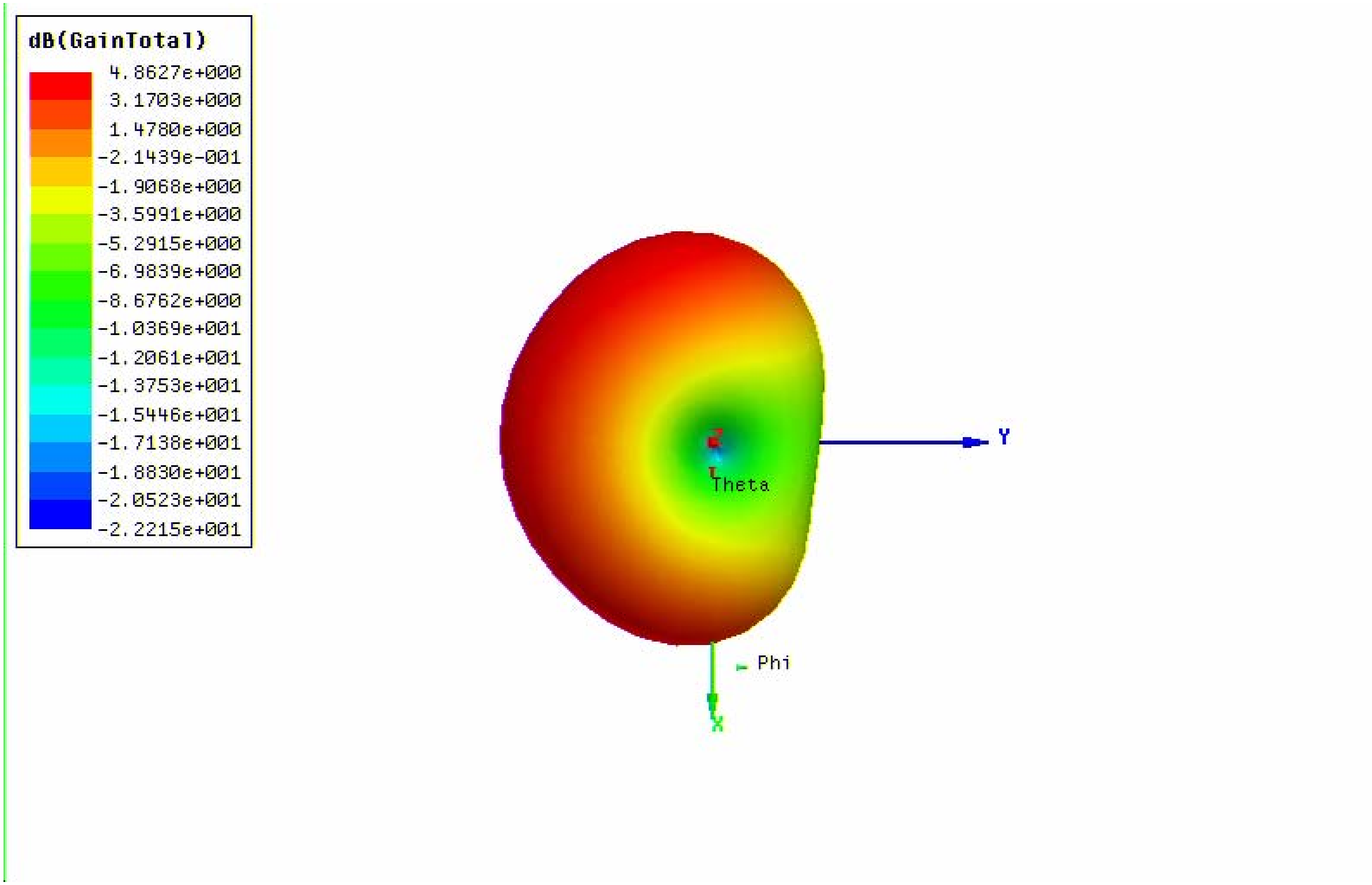


Figure 2-S. Top View– Dipole Array in Free Space (Side Feed-Point)

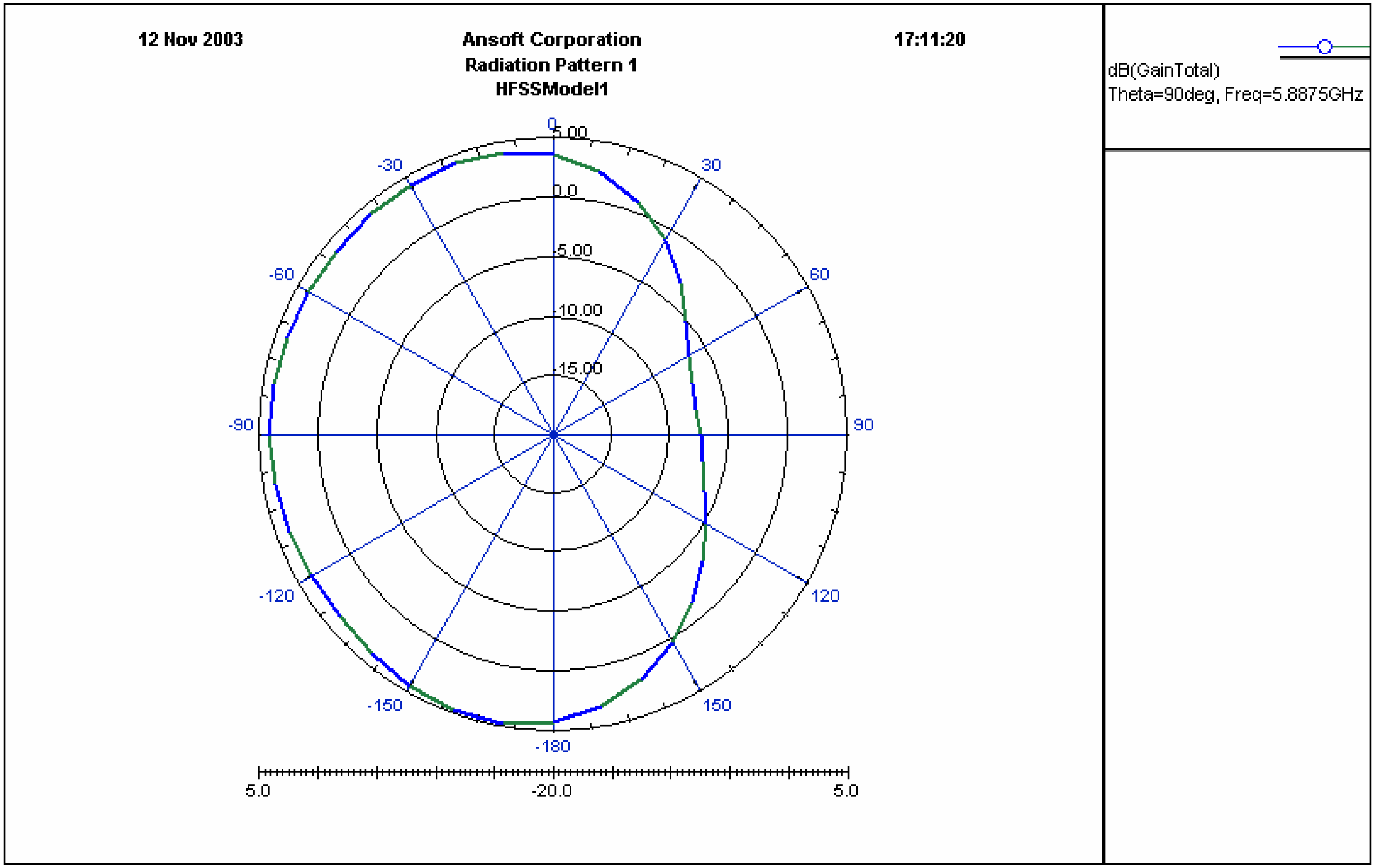


Figure 2-T. Radiation Pattern – Dipole Array in Free Space 0° Elevation (Side Feed-Point)

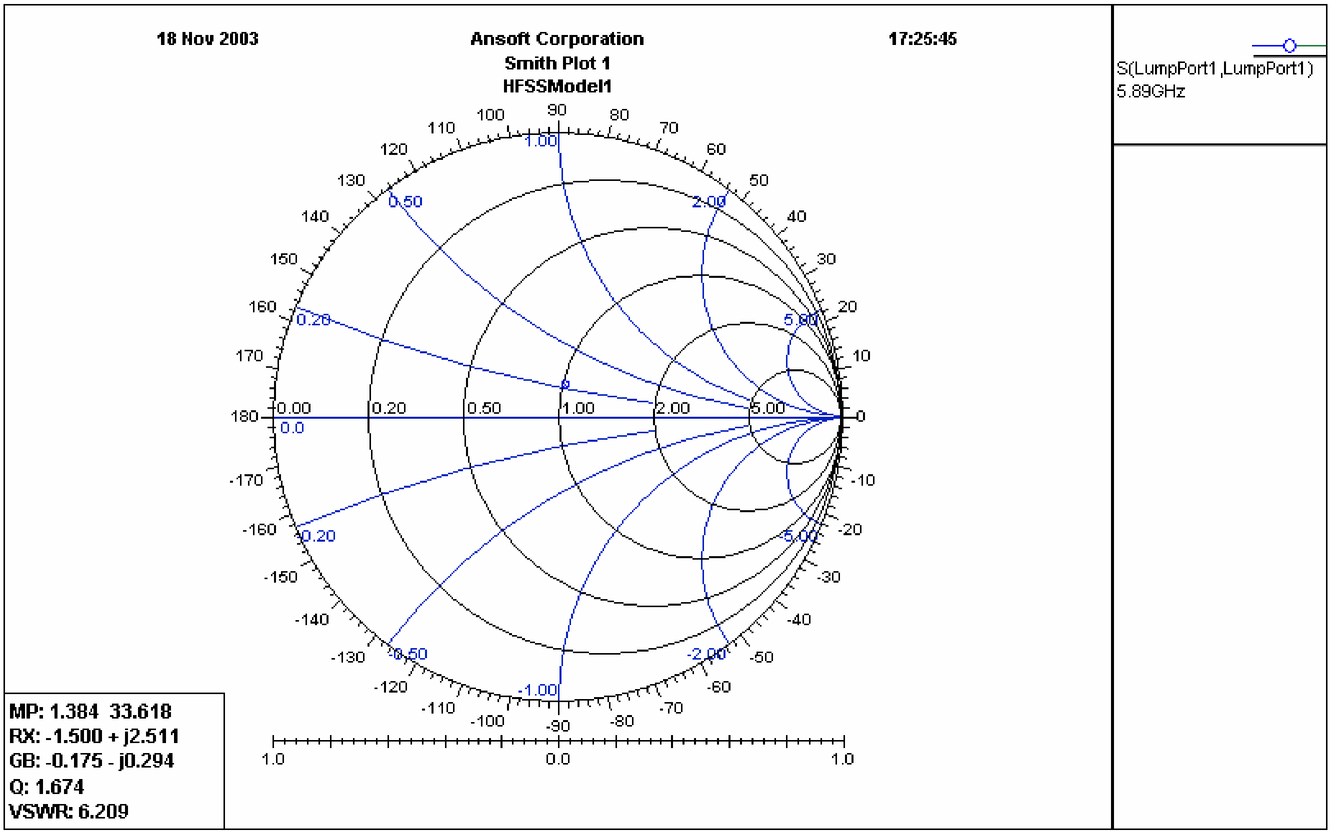


Figure 2-U. Smith Chart - Dipole Array in Free Space (Side Feed-Point)

The model simulation with the side feed-point did not impact the VSWR performance of the dipole array. The taper feed structure was tuned such that the input impedance was not affected.

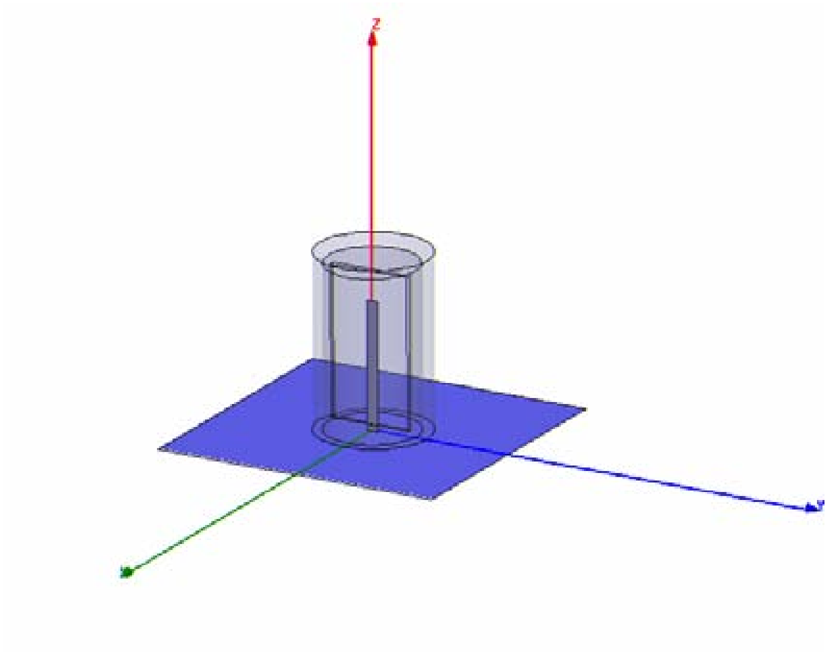
2.6 Roof-Mount Simulation

2.6.1 Design Description

Roof-mounted antenna design description:

- 5/8-wavelength element (internal element is approximately 1” tall).
- Requires approximately 2” radius of uninterrupted sheet metal surrounding the mounting location to serve as the ground plane.
- Overall omni-directional pattern at the required elevation angles.
- Geloy plastic radome (housing).
- Magnetic mounting mechanism with a coaxial pigtail parallel to the roof line.

2.6.2 Dimensioned Layout



The 5/8 wave element alone is approximately 26mm tall. It is modeled on a 14mm wide by 0.75mm thick substrate. The final shape and size of the antenna assembly will be determined by the mounting mechanism, appearance, and aerodynamics.

2.6.3 Model Assumptions

The HFSS model assumed that the antenna radome would be made of the GE plastic Geloy and mounted on a relatively flat conductive ground plane. In order to provide a more realistic model, both an infinite ground plane and a 300mm diameter ground plane simulation were run.

2.6.4 Infinite Ground Plan Pattern/Gain Plots

Gain plots and pattern measurements were simulated with the antenna element mounted on an infinite ground plane encased in a generic cylindrical Geloy radome. The results show a 5-8dB margin to the 0dBi requirement. The pattern is truncated below the horizon due to the theoretical assumption of the infinite ground plane. The presence of this ground plane also shifts the location of the peak gain closer towards the horizon.

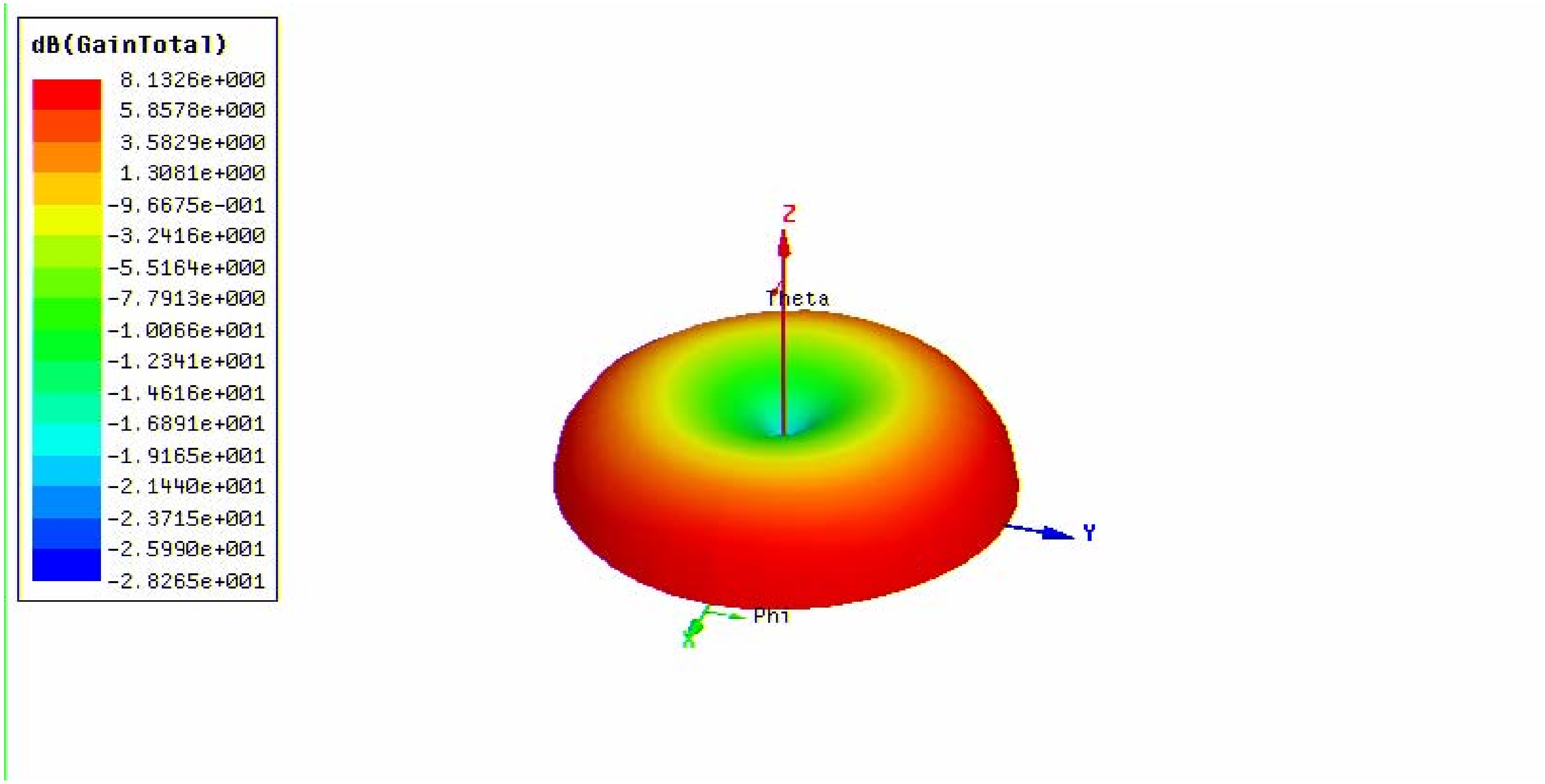


Figure 2-V. Isometric View – 5/8 Wave on Infinite Ground Plane

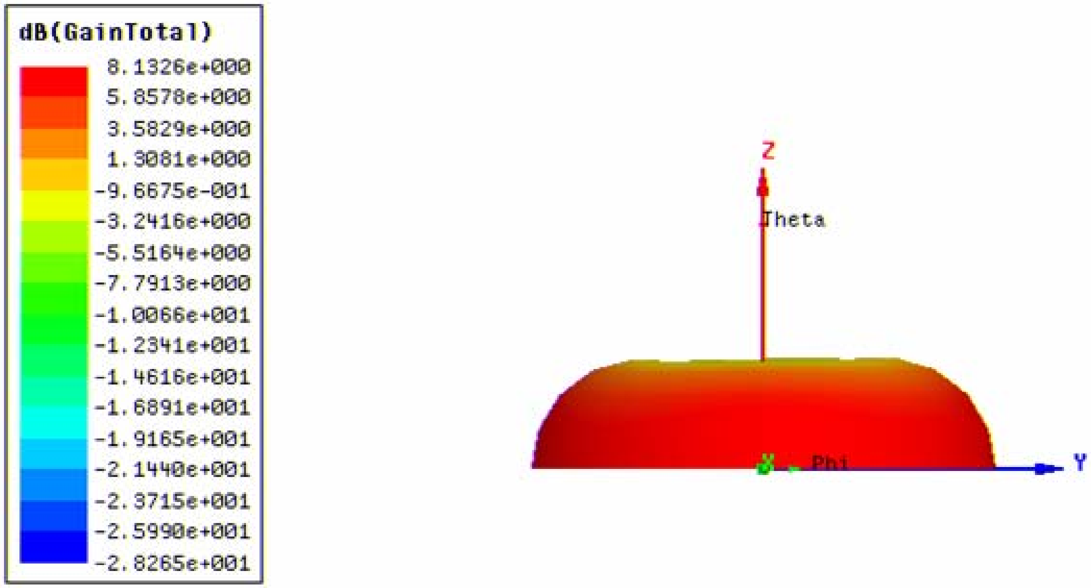


Figure 2-W. Side View – 5/8 Wave on Infinite Ground Plane

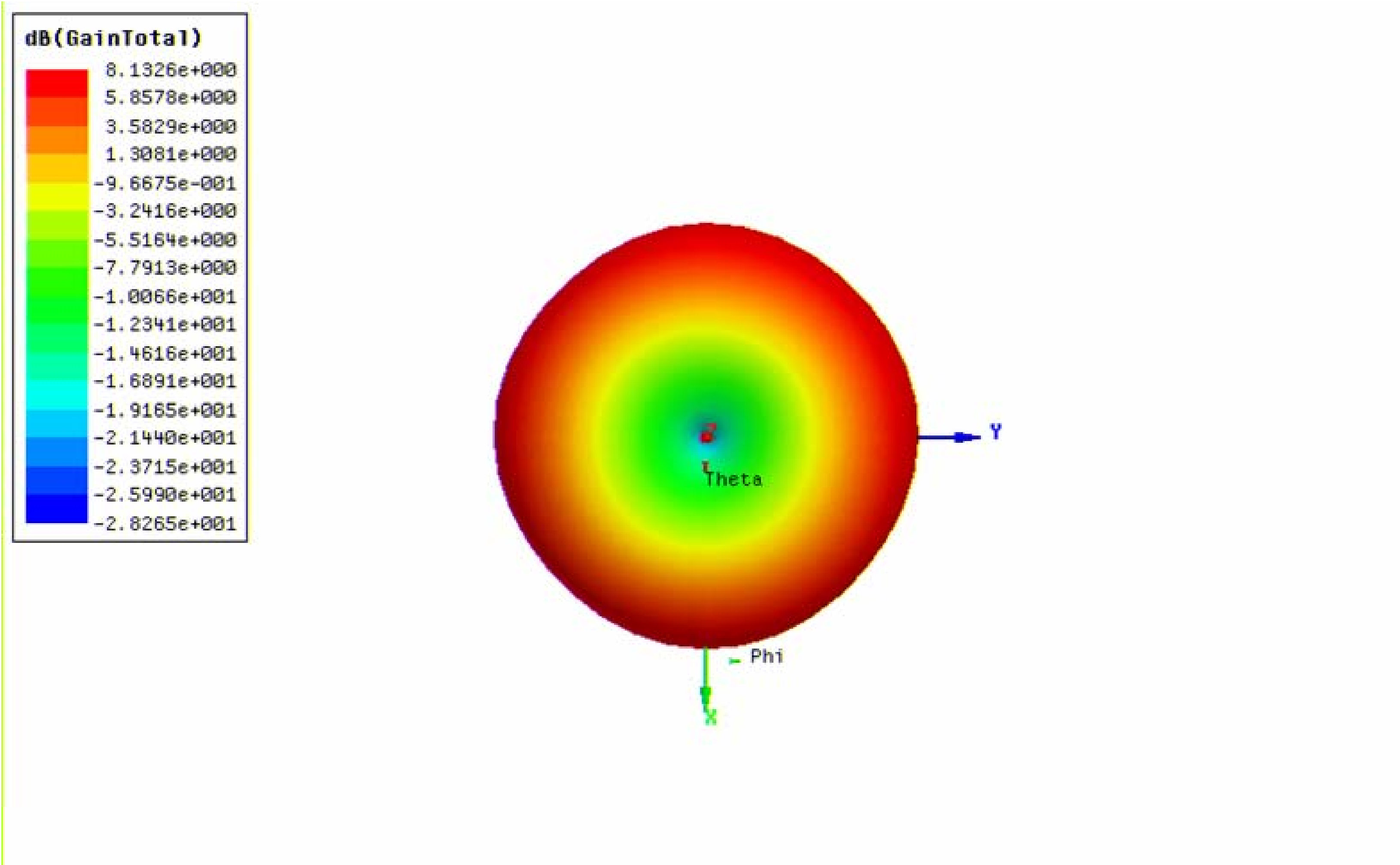


Figure 2-X. Top View – 5/8 Wave on Infinite Ground Plane

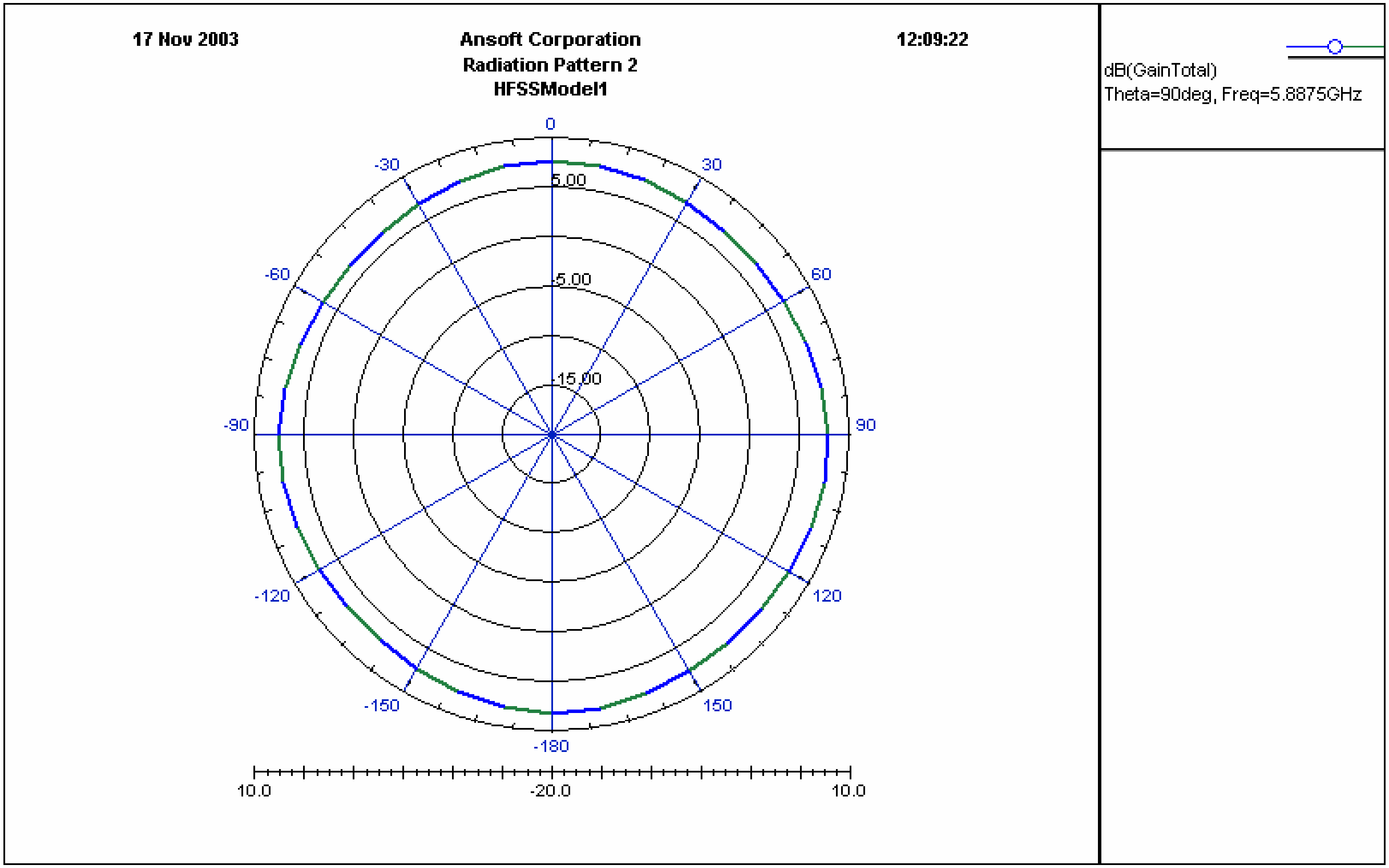
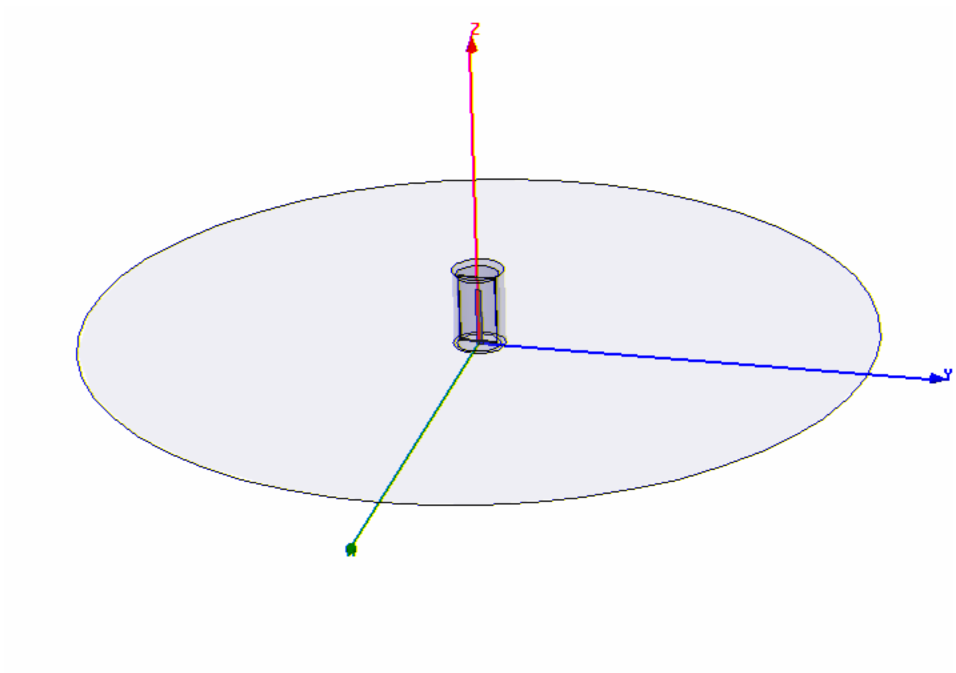


Figure 2-Y. Radiation Pattern - 5/8 Wave on Infinite Ground Plane 0° Elevation

2.6.5 300mm Ground Plan Pattern/Gain Plots

Gain plots and pattern measurements were also simulated with the antenna element encased in a generic cylindrical Geloy radome mounted in the center of a 300mm ground plane. The results show a minor reduction in overall gain, additional gain below the horizon and a shift in peak gain to approximately 30° above the horizon. The model still shows satisfactory gain with a ~2.5dB margin to the 0dBi requirement.



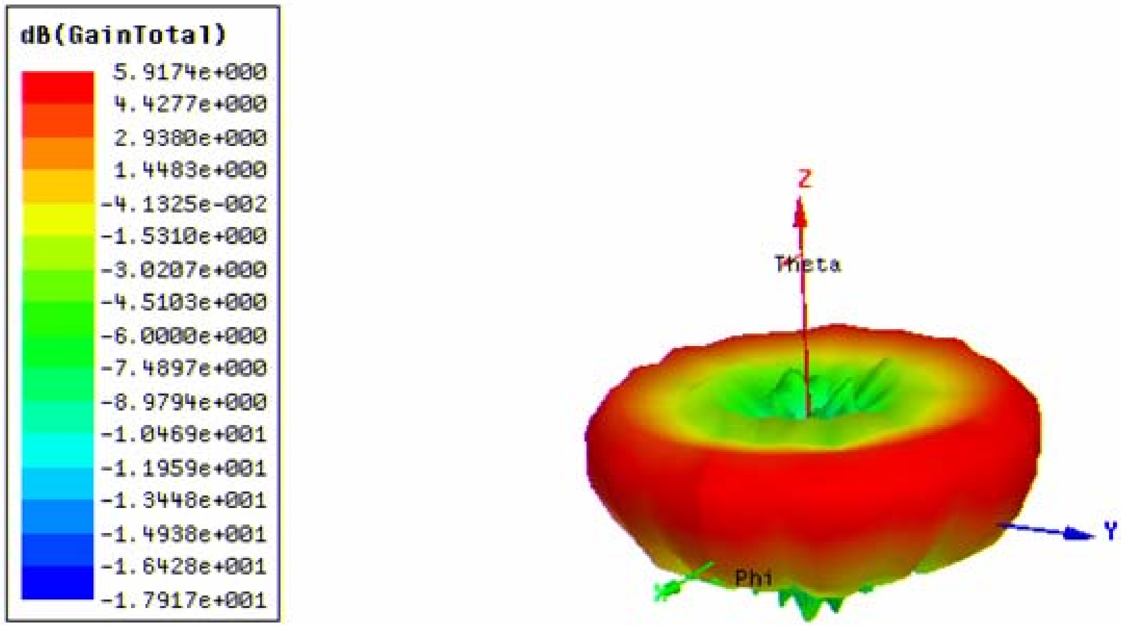


Figure 2-Z. Isometric View – 5/8 Wave on 300mm Ground Plane

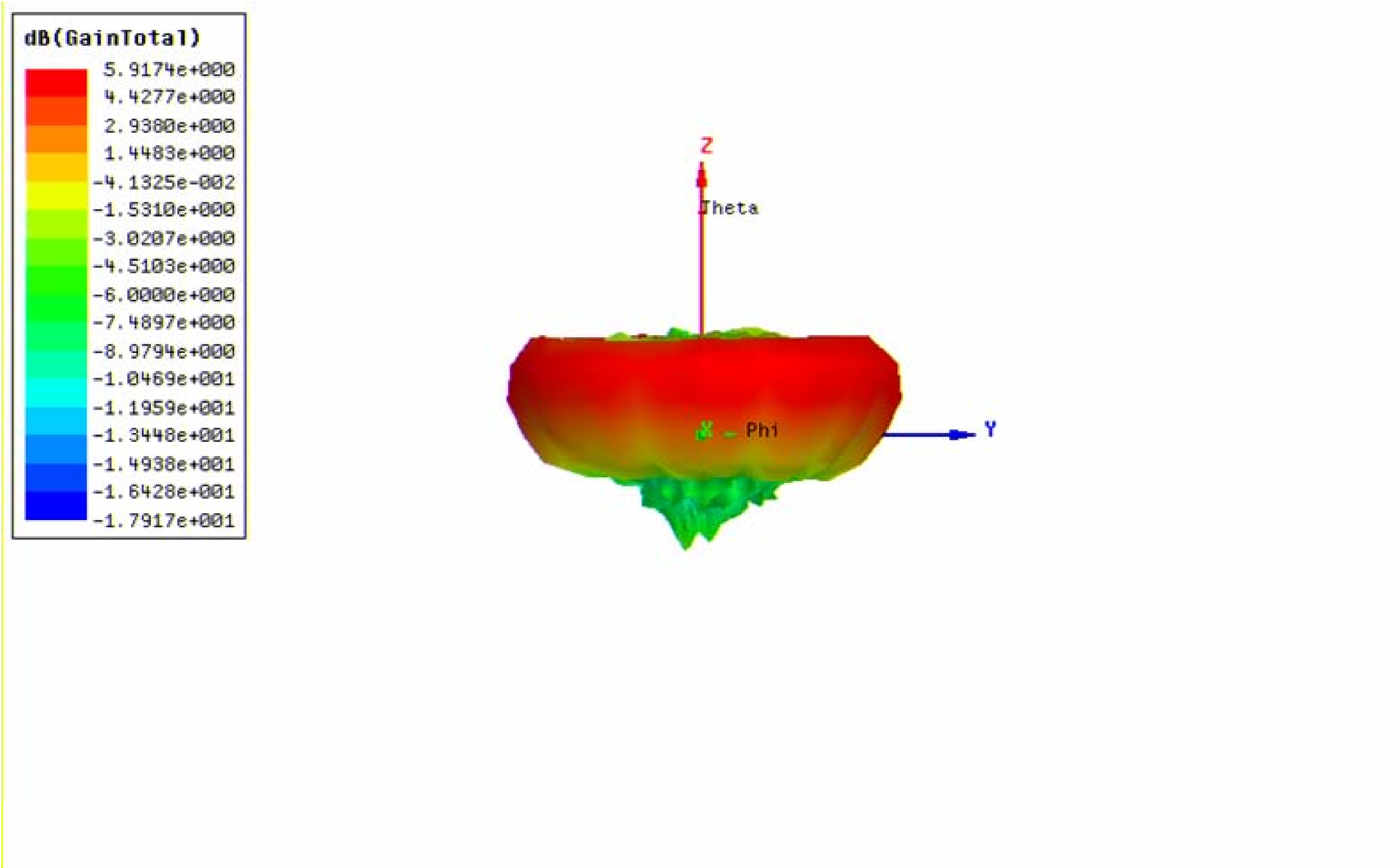


Figure 2-AA. Side View – 5/8 Wave on 300mm Ground Plane

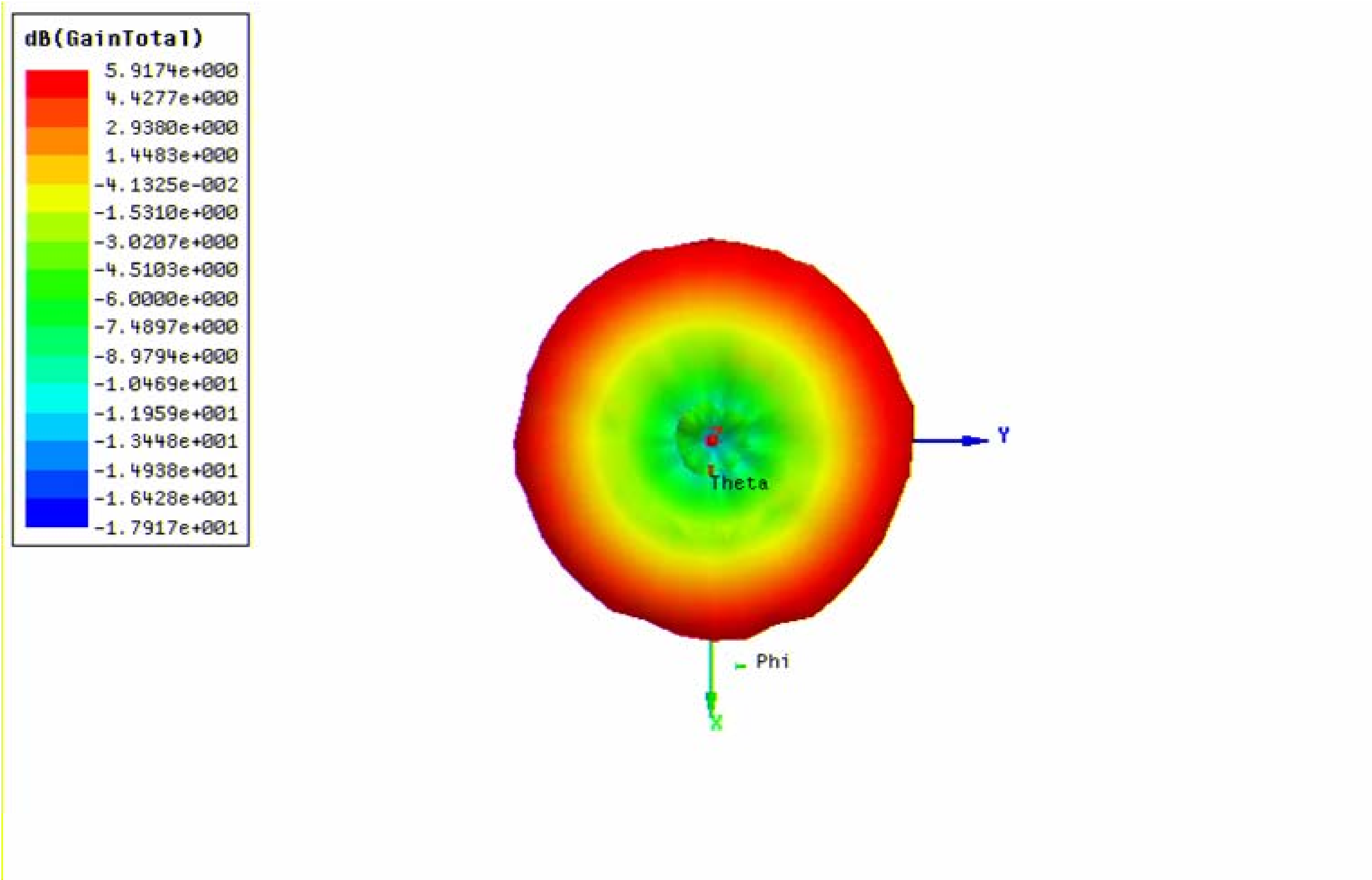


Figure 2-BB. Top View – 5/8 Wave on 300mm Ground Plane

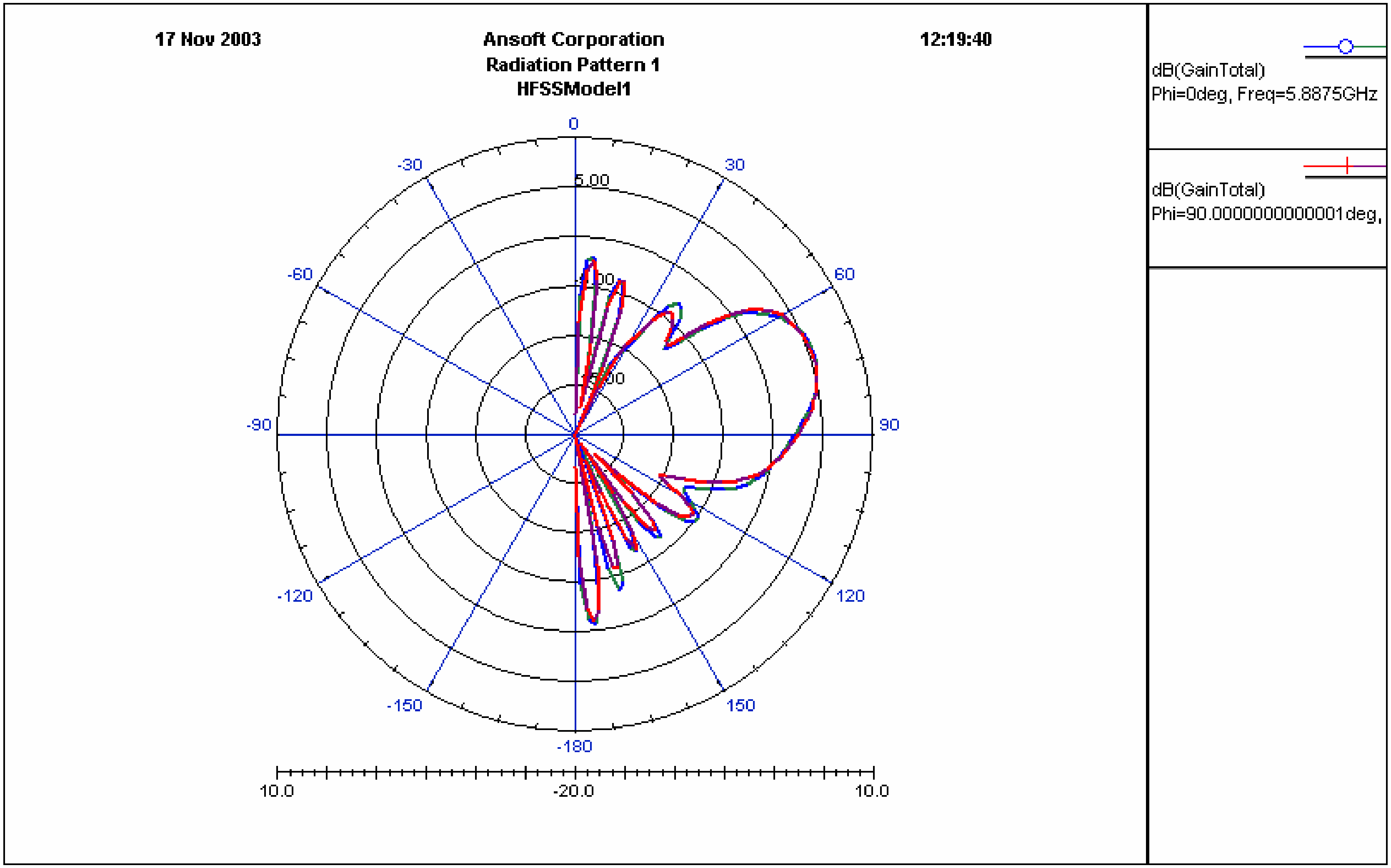


Figure 2-CC. Radiation Pattern - 5/8 Wave on 300mm Ground Plane Elevation Patterns at phi 0 (XZ) and 90 (YZ) Degrees

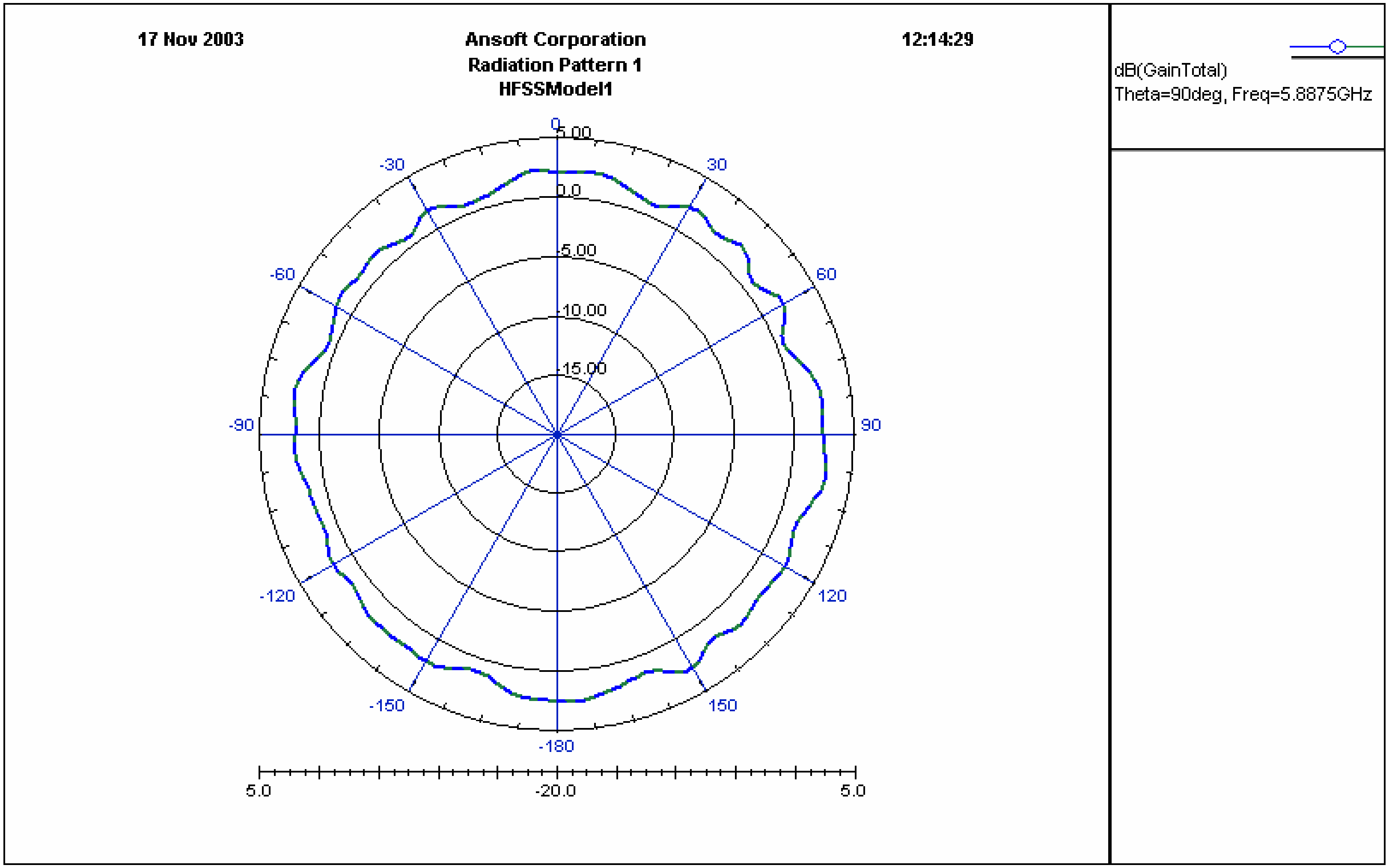


Figure 2-DD. Radiation Pattern - 5/8 Wave on 300mm Ground Plane 70° Elevation

2.7 Free-Space Link Budget

In order to demonstrate that the theoretical designs would be capable of system operation a free-space link budget calculator was developed. Three nominal cases were simulated: mirror-to-mirror, roof-to-roof, and mirror-to-roof. All calculations resulted in at least 3dB margin for the system.

Assumptions used in the model:

- 100mW transmit power
- 3.0dB cable loss for both transmit and receive systems
- 500m max range
- -86dBm receiver sensitivity (based on Atheros chip set)
- Mirror (dipole) gain 3.0dB
- Roof (5/8 wave) gain 2.5dB
- Multi-path nulls are not simulated

The specific cable routing is dependent on the individual vehicle structures and locations of the test equipment. The following calculations show a typical Thermax 0.070" antenna pigtail with a transition to LMR195 internal to the vehicle for additional length.

Cable loss calculations

Type	Loss / ft @5.8GHz	Length ft.	loss
0.070 cable	0.96	1.5	1.44 dB
LMR 195	0.28	5	1.4 dB
		Total loss	2.84 dB

Note: If a single cable type is used the maximum length of 0.070" cable is ~3 feet and maximum length of LMR195 is 10.5 feet.

2.7.1 Free-Space Link Budget (Mirror-to-Mirror)

	Inputs	
Frequency (GHz)	5.89	
Transmit power (mW)	100.00	20 (dBm)
cable loss, dB	3.00	
TX antenna gain (dBi)	3.00	
Range (M)	500.00	-101.82 (Path loss, dB)
RX antenna gain (dbi)	3.00	
cable loss, dB	3.00	
RX sensitivity (dBm)	-86.00	

Net RX power	-81.82 dBm	Link success
Link margin	4.18 DB	

2.7.2 Free-Space Link Budget (Mirror-to-Roof)

	Inputs	
Frequency (GHz)	5.89	
Transmit power (mW)	100.00	20 (dBm)
cable loss, dB	3.00	
TX antenna gain (dBi)	3.00	
Range (M)	500.00	-101.82 (Path loss, dB)
RX antenna gain (dbi)	2.50	
cable loss, dB	3.00	
RX sensitivity (dBm)	-86.00	

Net RX power	-82.32 dBm	Link success
Link margin	3.68 DB	

2.7.3 Free-Space Link Budget (Roof-to-Roof)

	Inputs		
Frequency (GHz)	5.89		
Transmit power (mW)	100.00	20	(dBm)
cable loss, dB	3.00		
TX antenna gain (dBi)	2.50		
Range (M)	500.00	-101.82	(Path loss, dB)
RX antenna gain (dbi)	2.50		
cable loss, dB	3.00		
RX sensitivity (dBm)	-86.00		
Net RX power	-82.82 dBm	Link success	
Link margin	3.18 dB		

2.8 Summary

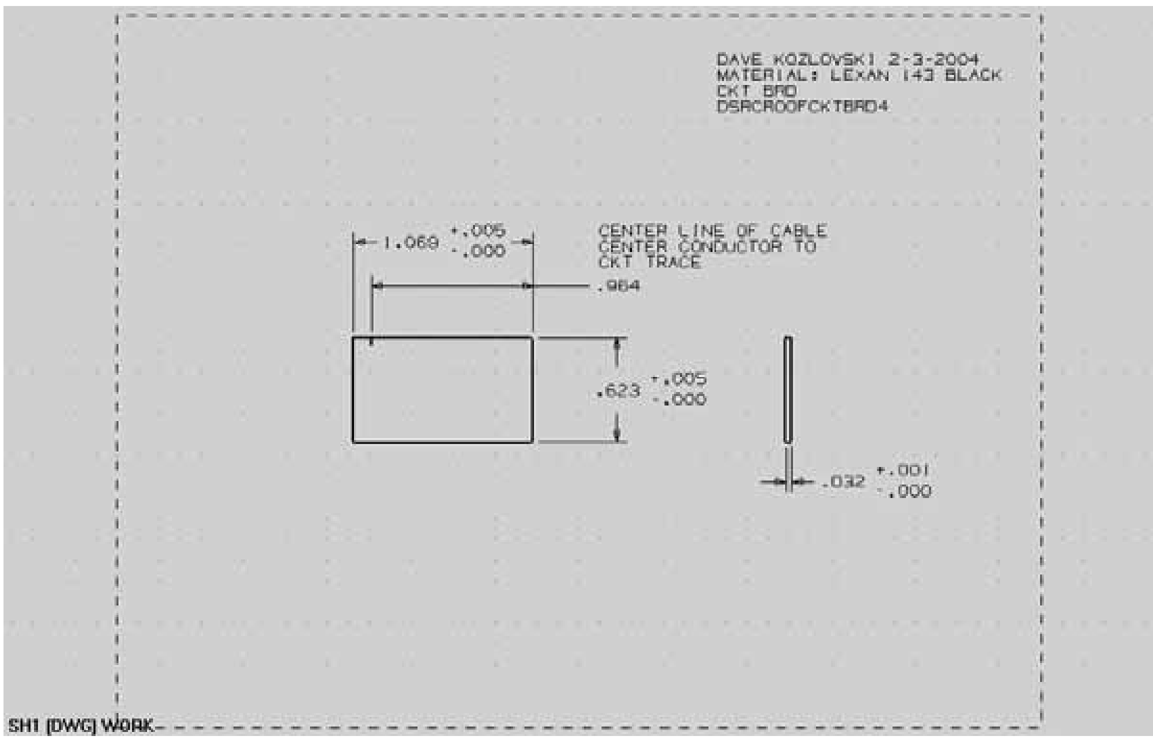
M/A-COM has achieved, on other projects, very comparable results between the theoretical modeling in HFSS and prototype component testing. These results are limited to the processing capability and the model assumptions used with the software. We do however feel confident that there is sufficient margin between the simulation and the design specification to ensure satisfactory actual antenna performance.

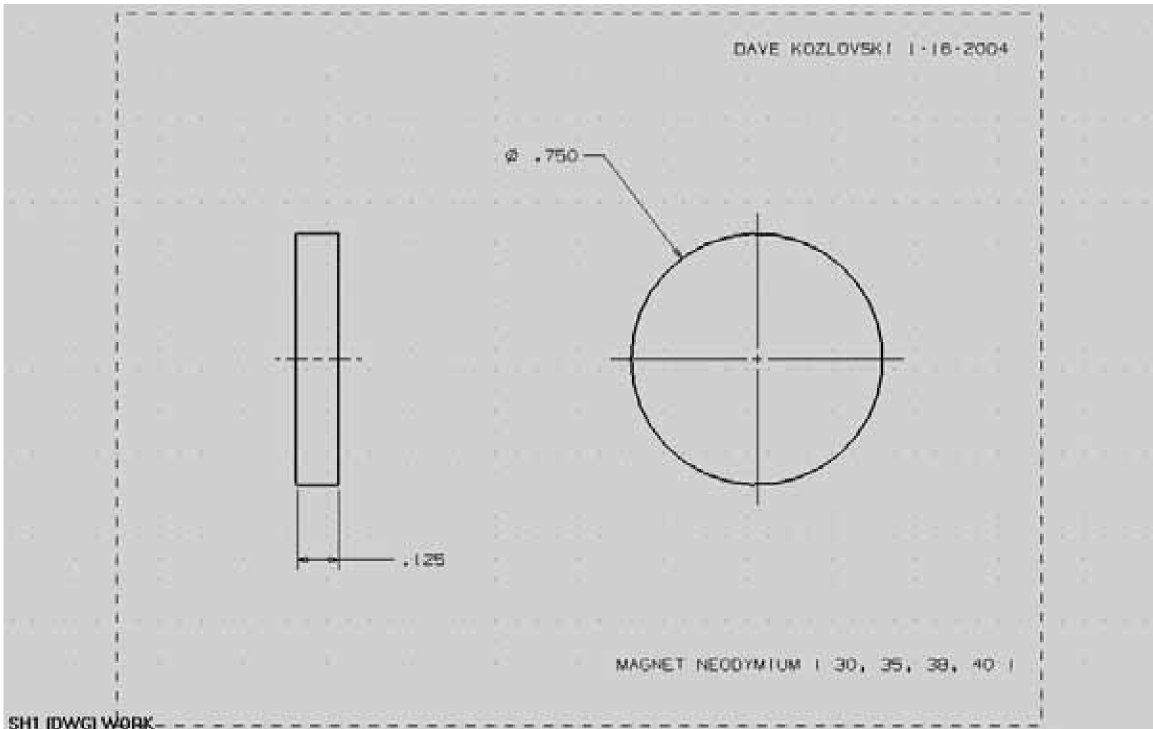
3 Antenna Subproject Final Report

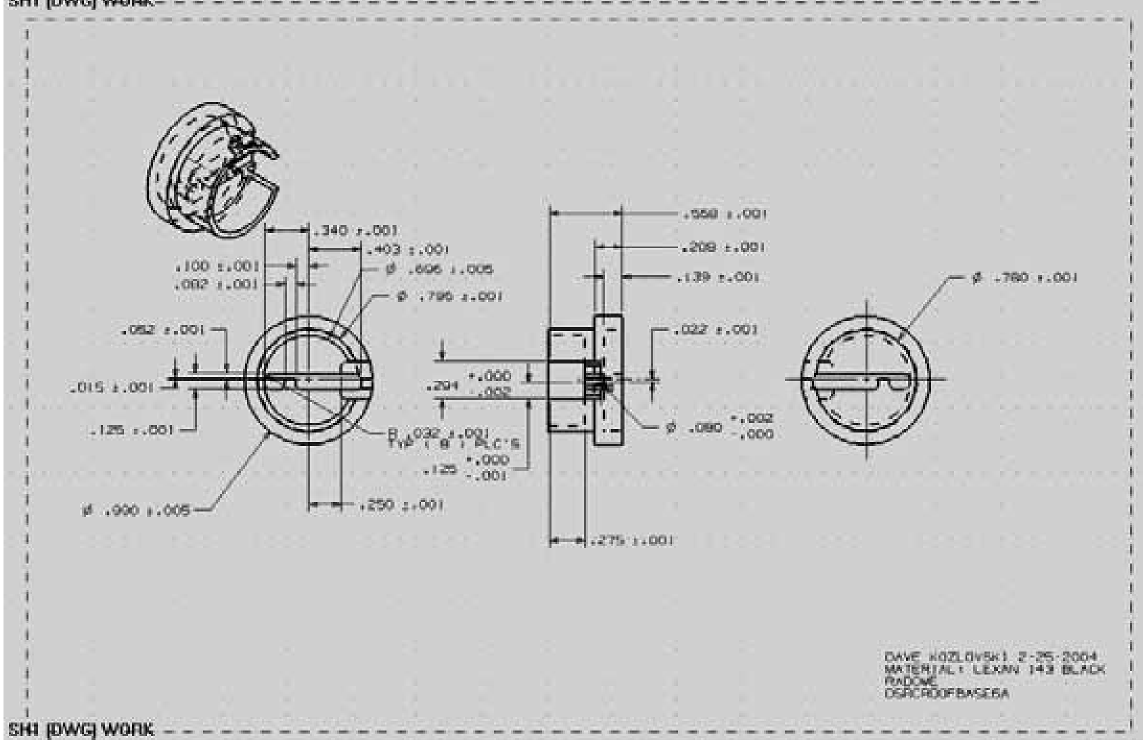
This final report describes measured test results of two antenna designs in support of Task 6C of the Collision Avoidance Metrics Program (CAMP) Vehicle Safety Communications (VSC) project. Antennas were designed for application to the vehicle side view mirror and roof locations for operation within the 5.85 to 5.925 GHz Intelligent Transportation System (ITS) Dedicated Short Range Communications (DSRC) band.

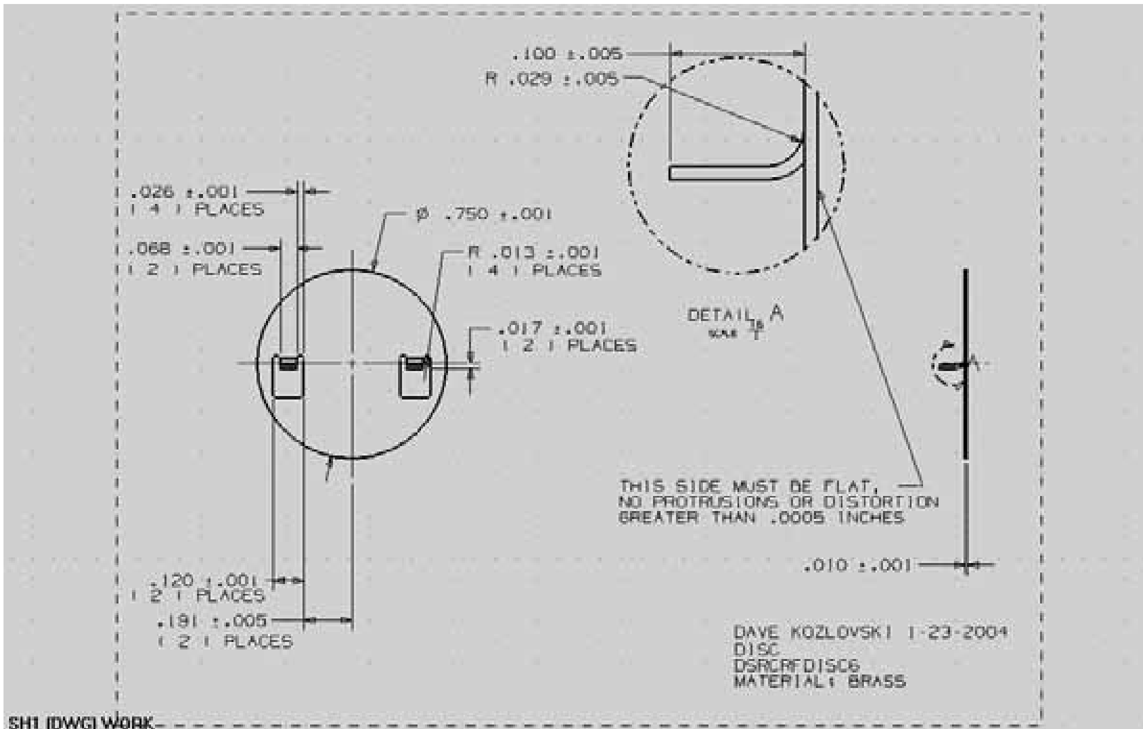
3.1 Antenna Design

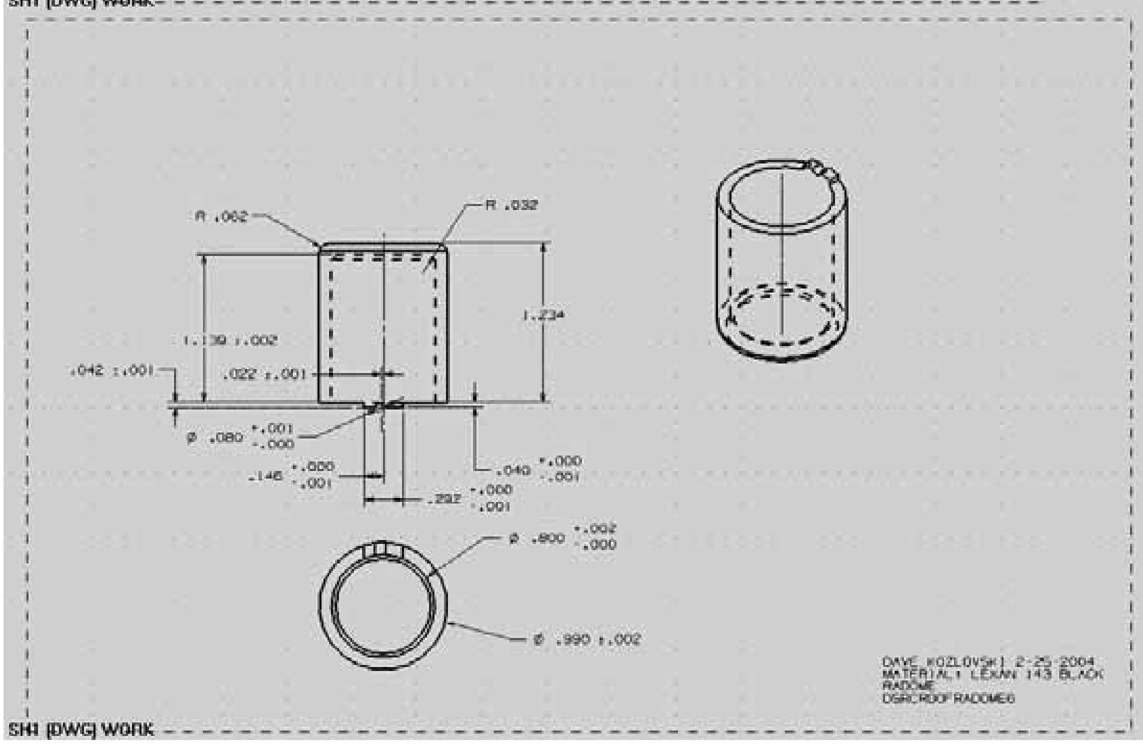
3.1.1 Magnetic Roof Mount Antenna Drawings

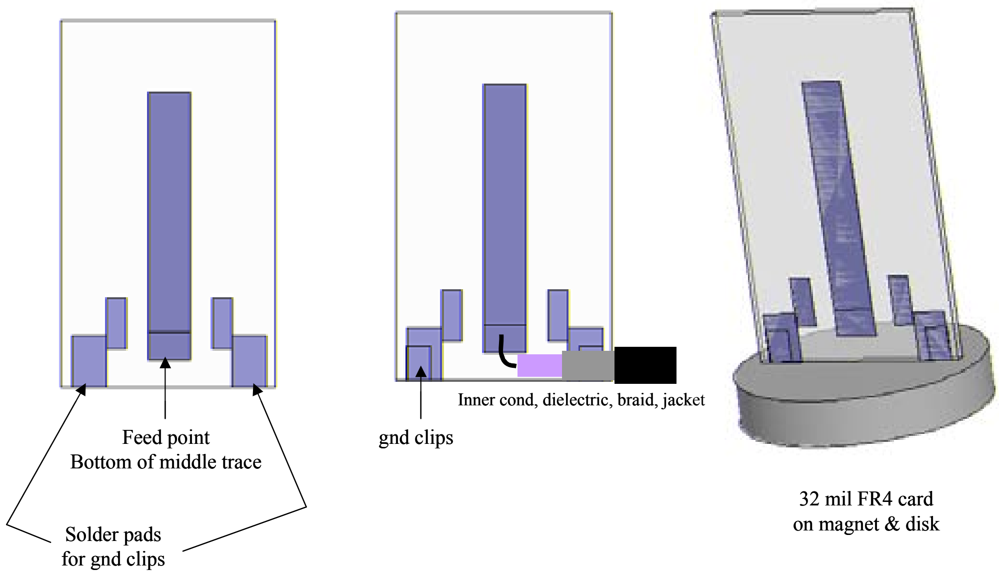


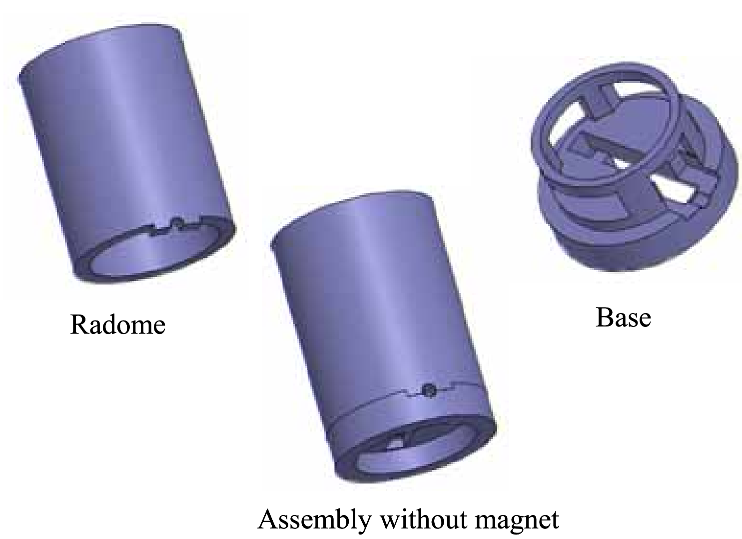

DAVE KOZLOVSKI 1-16-2004
Ø .750
.125
MAGNET NEODYMIUM (30, 35, 38, 40)
SH1 [DWG] WORK

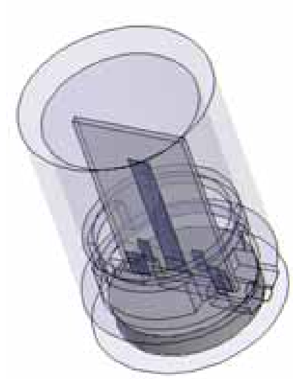

.340 ±.001
.403 ±.001
.100 ±.001
.082 ±.001
Ø .696 ±.005
Ø .796 ±.001
.082 ±.001
.015 ±.001
.125 ±.001
R .032 ±.001
TYP (8) PLC'S
Ø .900 ±.005
.250 ±.001
.558 ±.001
.209 ±.001
.139 ±.001
.022 ±.001
.294 +.000 -.002
.125 +.000 -.001
Ø .080 +.002 -.000
.275 ±.001
Ø .780 ±.001
DAVE KOZLOVSKI 2-25-2004
MATERIAL: LEXAN 143 BLACK
RADOME
OSRCROOFBASE6A
SH1 [DWG] WORK


.100 ±.005
R .029 ±.005
.026 ±.001
(4) PLACES
Ø .750 ±.001
.068 ±.001
(2) PLACES
R .013 ±.001
(4) PLACES
.017 ±.001
(2) PLACES
DETAIL A
THIS SIDE MUST BE FLAT,
NO PROTRUSIONS OR DISTORTION
GREATER THAN .0005 INCHES
.010 ±.001
.120 ±.001
(2) PLACES
.191 ±.005
(2) PLACES
DAVE KOZLOVSKI 1-23-2004
DISC
DSRCRFDISC6
MATERIAL: BRASS
SH1 (DWG) WORK


R .062
R .032
1.234
.042 ±.001
.022 ±.001
Ø .080
.040
.292
Ø .990 ±.002
DAVE KOZLOVSKI 2-25-2004
MATERIAL: LEXAN 143 BLACK
RADOME
SH1 (DWG) WORK

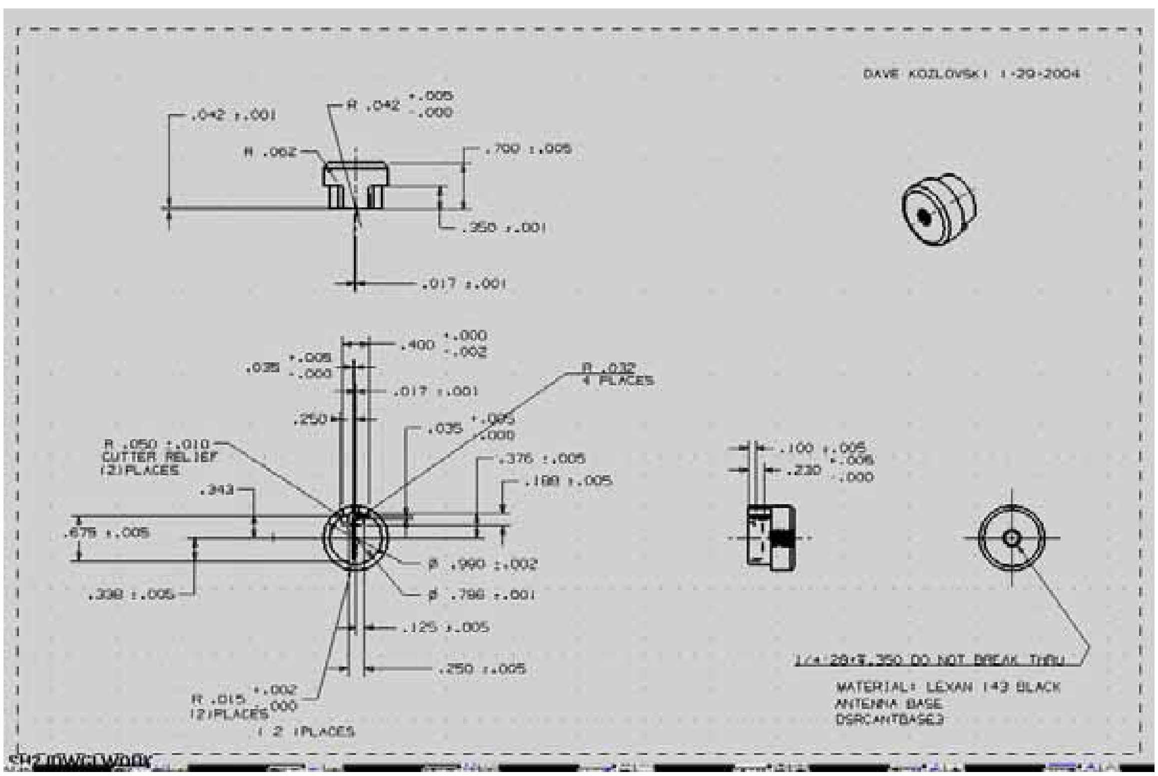

Inner cond, dielectric, braid, jacket
gnd clips
Feed point
Bottom of middle trace
Solder pads
for gnd clips
32 mil FR4 card
on magnet & disk

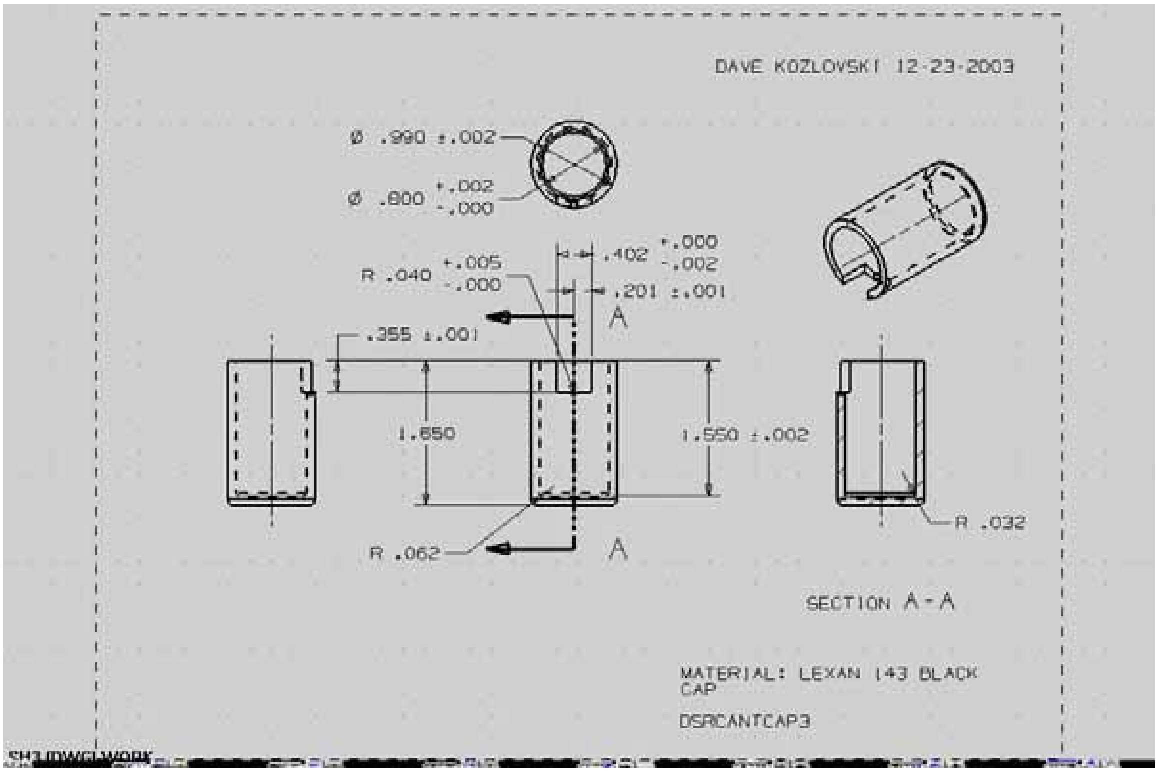

Radome
Base
Assembly without magnet

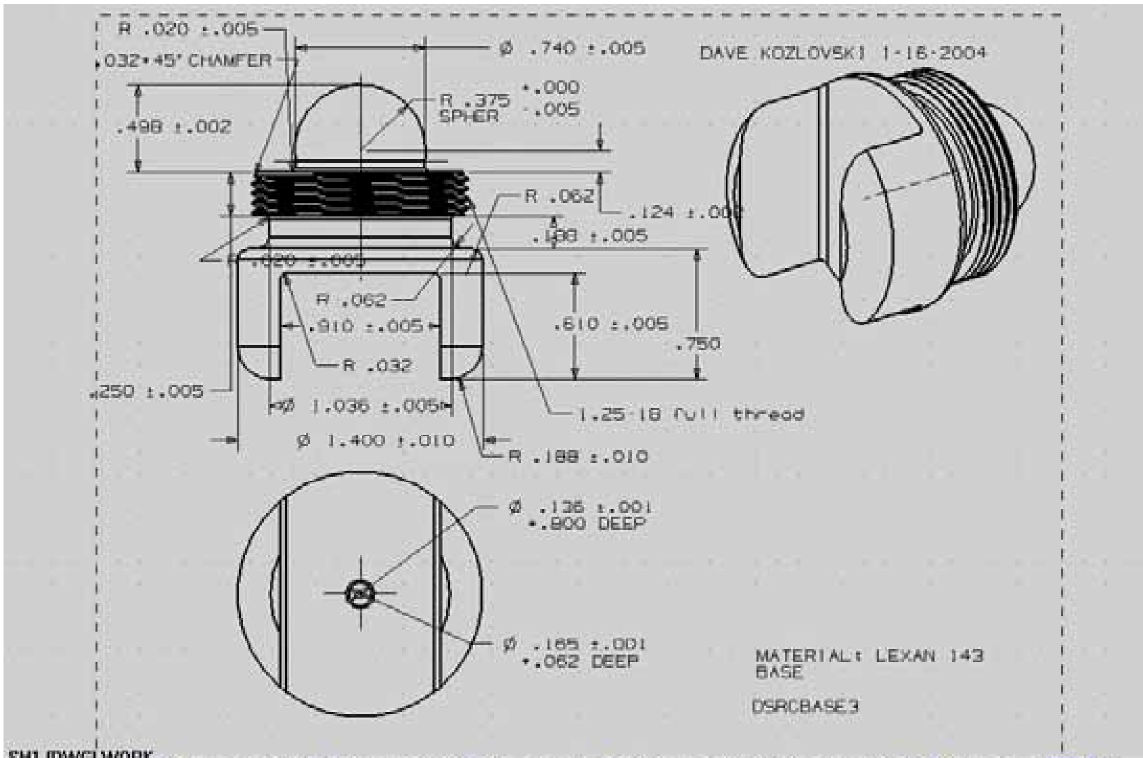


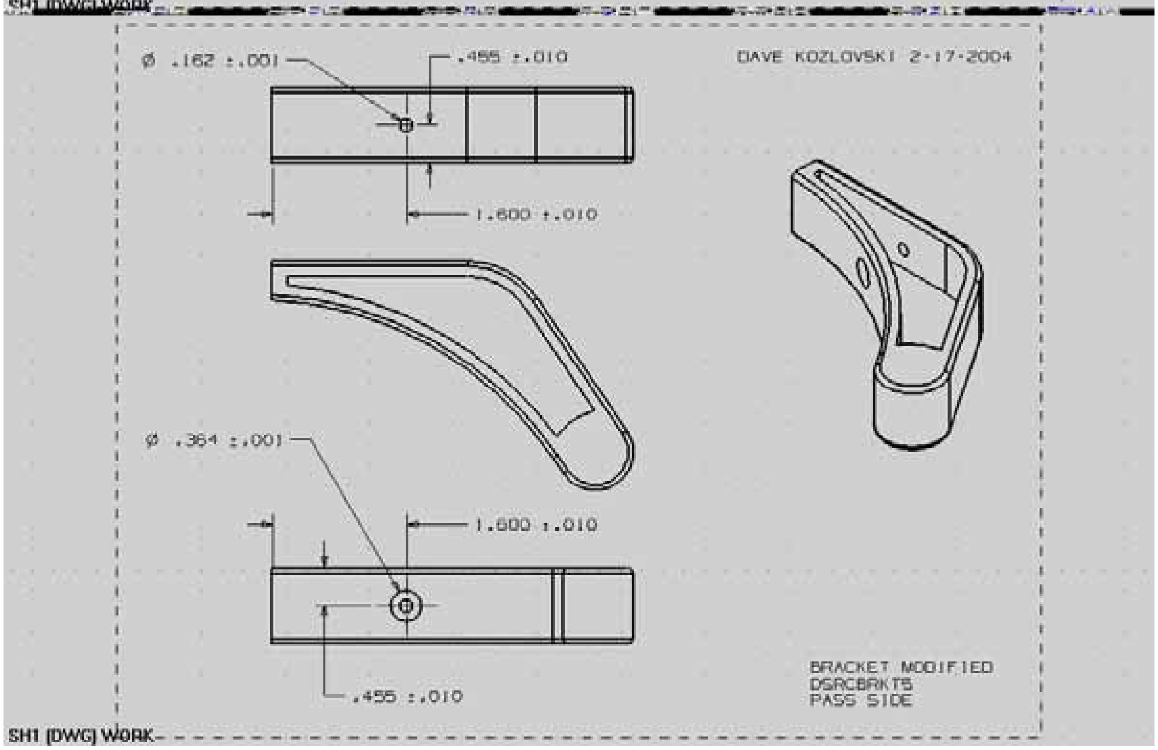
Complete assembly

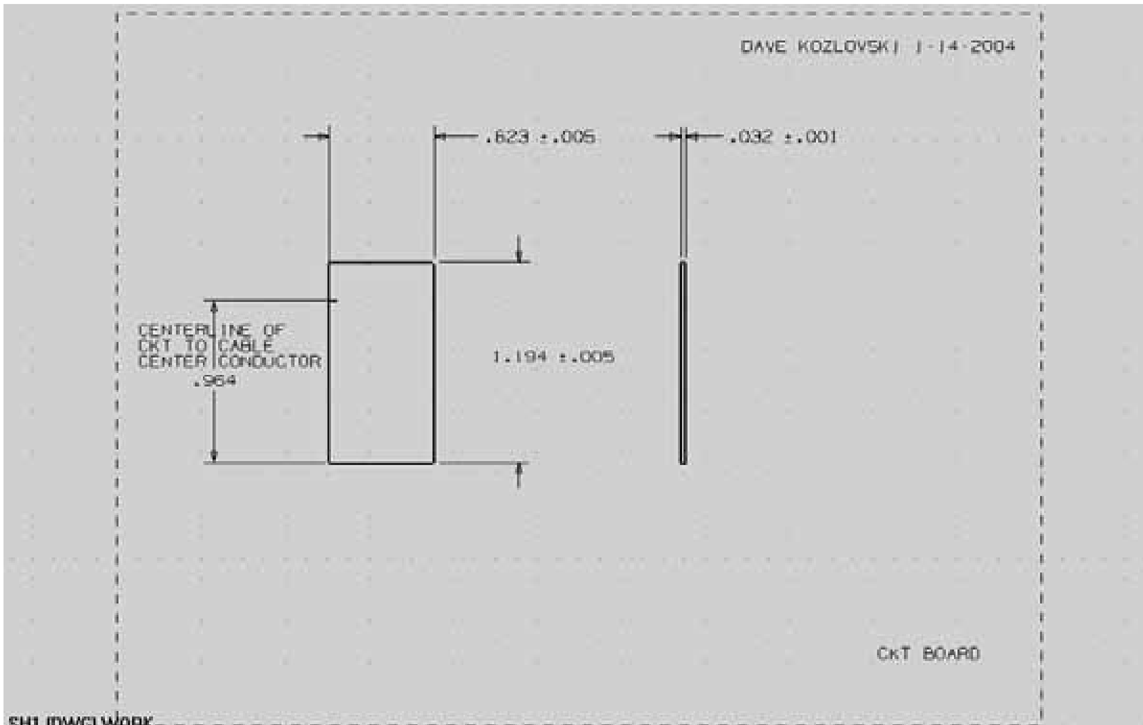
3.1.2 Mirror Antenna Drawings

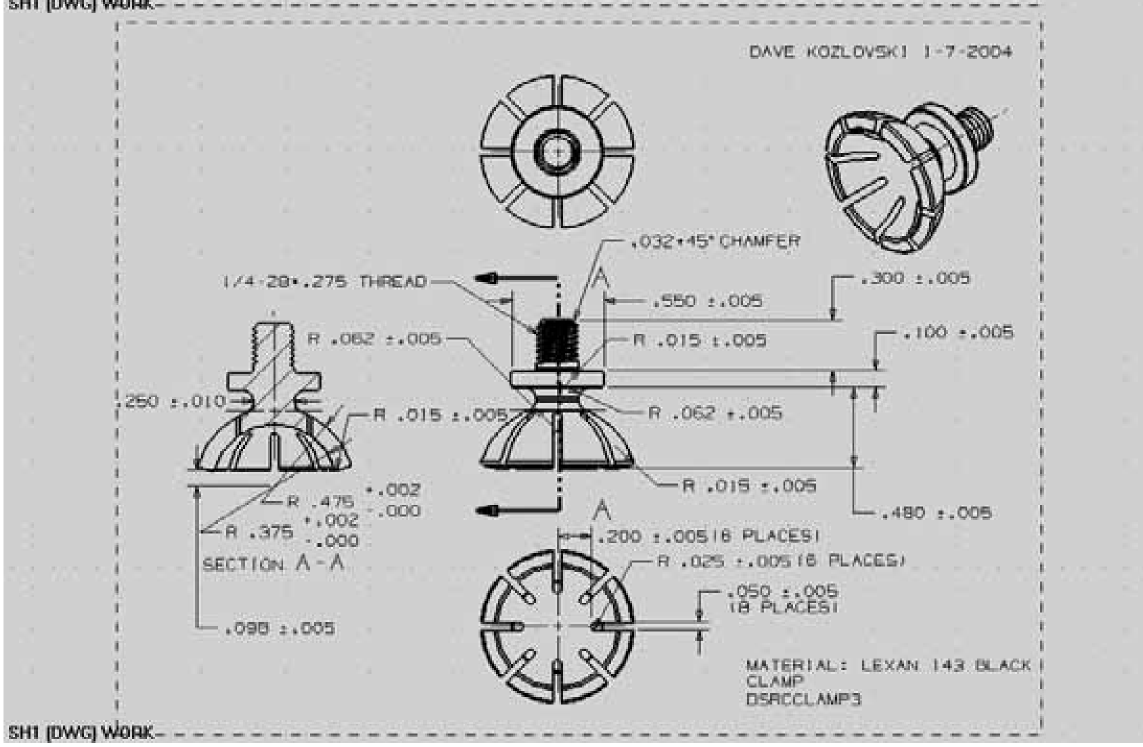


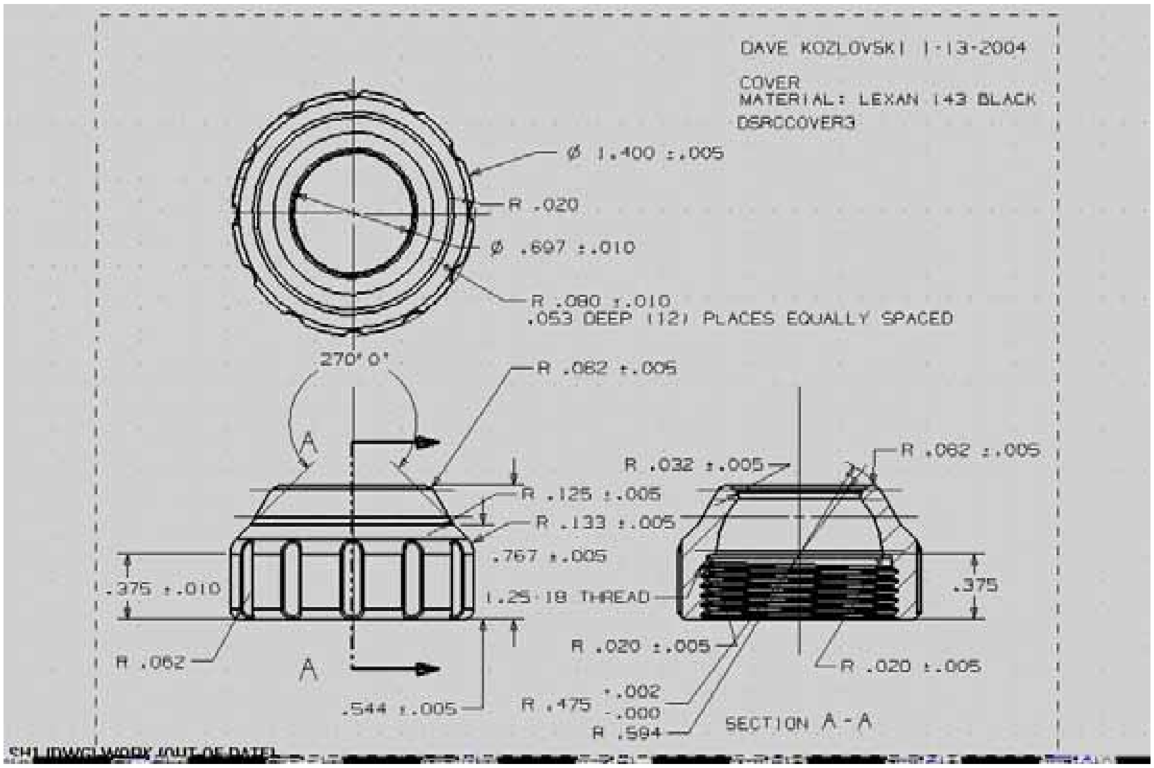

DAVE KOZLOVSKI 12-23-2003
Ø .990 ±.002
Ø .800 +.002 -.000
.402 +.000 -.002
R .040 +.005 -.000
.201 ±.001
A
.355 ±.001
1.650
1.550 ±.002
R .032
R .062
A
SECTION A-A
MATERIAL: LEXAN 143 BLACK
CAP
DSRCANTCAP3


R .020 ±.005
.032×45° CHAMFER
Ø .740 ±.005
DAVE KOZLOVSKI 1-16-2004
.498 ±.002
R .375 SPHER
+.000
-.005
R .062
.124 ±.00
.188 ±.005
R .062
.910 ±.005
.610 ±.005
.750
R .032
.250 ±.005
Ø 1.036 ±.005
1.25-18 full thread
Ø 1.400 ±.010
R .188 ±.010
Ø .136 ±.001
▼.800 DEEP
Ø .165 ±.001
▼.062 DEEP
MATERIAL: LEXAN 143
BASE
DSRCBASE3

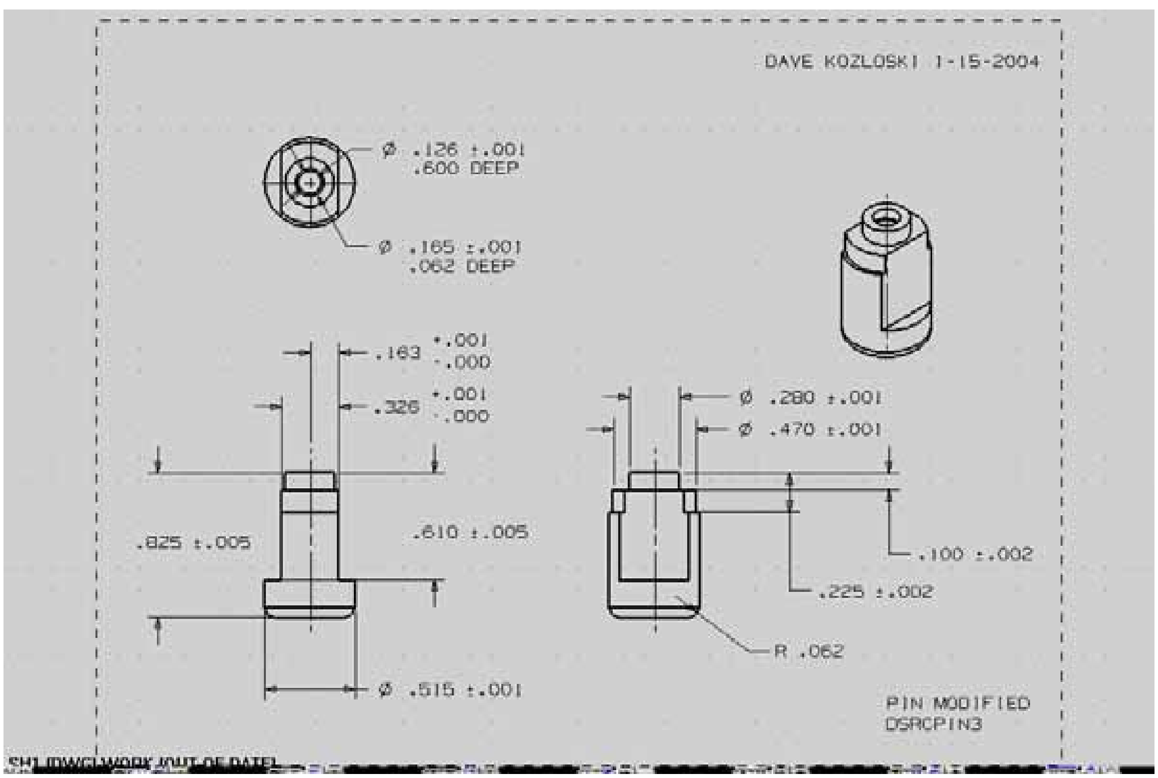

Ø .162 ±.001
.455 ±.010
DAVE KOZLOVSKI 2-17-2004
1.600 ±.010
Ø .364 ±.001
1.600 ±.010
.455 ±.010
BRACKET MODIFIED
DSRCBRKT5
PASS SIDE
SH1 (DWG) WORK


DAVE KOZLOVSKI 1-14-2004
.623 ±.005
.032 ±.001
CENTERLINE OF CKT TO CABLE CENTER CONDUCTOR
.964
1.194 ±.005
CKT BOARD
SH1 [DWG] WORK


DAVE KOZLOVSKI 1-7-2004
.032×45° CHAMFER
1/4-28×.275 THREAD
.300 ±.005
.550 ±.005
R .062 ±.005
R .015 ±.005
.100 ±.005
.250 ±.010
R .015 ±.005
R .062 ±.005
R .015 ±.005
R .475 +.002 -.000
R .375 +.002 -.000
.480 ±.005
SECTION A-A
.200 ±.005 (8 PLACES)
R .025 ±.005 (8 PLACES)
.050 ±.005 (8 PLACES)
.095 ±.005
MATERIAL: LEXAN 143 BLACK
CLAMP
DSRCCLAMP3
SH1 [DWG] WORK



DAVE KOZLOVSKI 1-13-2004
COVER
MATERIAL: LEXAN 143 BLACK
DSRCCOVER3
Ø 1.400 ±.005
R .020
Ø .697 ±.010
R .080 ±.010
.053 DEEP (12) PLACES EQUALLY SPACED
270°0'
R .062 ±.005
R .032 ±.005
R .062 ±.005
R .125 ±.005
R .133 ±.005
.767 ±.005
.375 ±.010
1.25-18 THREAD
.375
R .062
R .020 ±.005
R .020 ±.005
.544 ±.005
R .475 +.002 -.000
R .594
SECTION A-A
SH1 [DWG] WORK [OUT OF DATE]



DAVE KOZLOSKI 1-15-2004
Ø .126 ±.001
.600 DEEP
Ø .165 ±.001
.062 DEEP
.163 +.001 -.000
.326 +.001 -.000
Ø .280 ±.001
Ø .470 ±.001
.825 ±.005
.610 ±.005
.100 ±.002
.225 ±.002
R .062
Ø .515 ±.001
PIN MODIFIED
DSRCPIN3
SH1 [DWG] WORK [OUT OF DATE]

3.2 Anechoic Chamber and Bench Test Data

3.2.1 Chamber Characteristics

Radiation pattern measurements were conducted in an anechoic chamber located at M/A-COM headquarters in Lowell, MA. The anechoic chamber used for these measurements is a 30 foot long tapered chamber including a 12 ft. x 12 ft. test box having a 4 ft quiet zone.

3.2.1.1 Gain – Mirror Mount Antenna

The mirror mount antenna including its radome and 2-foot long coaxial pigtail were placed in a free-space configuration in the anechoic chamber. The vertically polarized antenna gain was measured at a frequency of 5.9GHz. Because the 2-foot coaxial pigtail is an integral part of the antenna, the measured gain includes the 2dB loss of the coaxial pigtail. The azimuth gain pattern shown in Figure 35 was measured by rotating the antenna on its vertical axis. The elevation pattern shown in Figure 36 was measured by rotating the antenna along the horizontal.

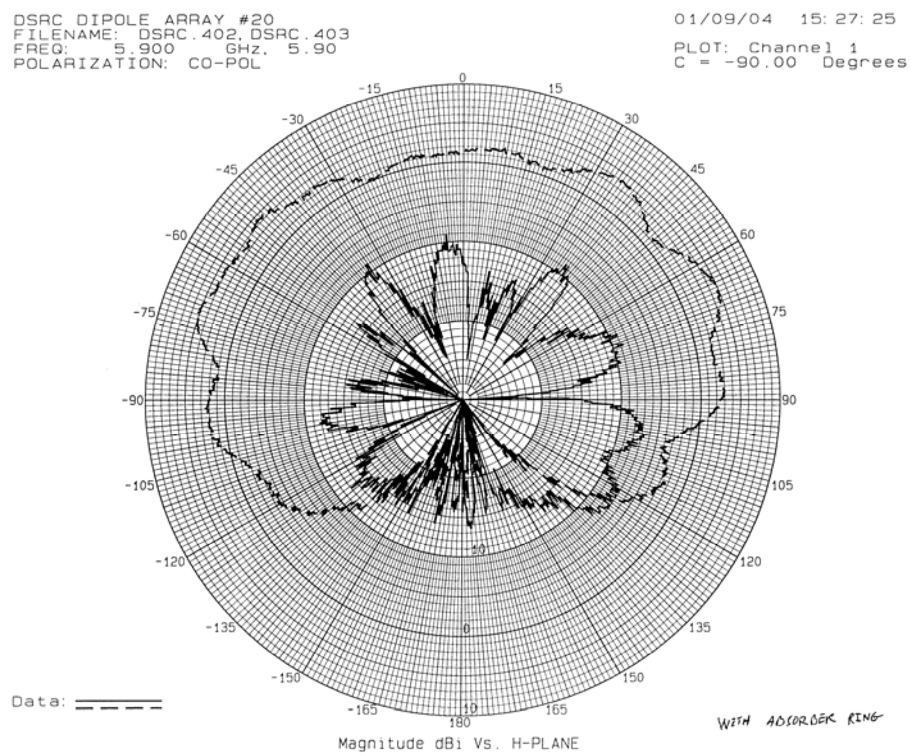


Figure 3-A. Azimuth Radiation Pattern of the Mirror Mount Antenna Including 2dB Cable Loss

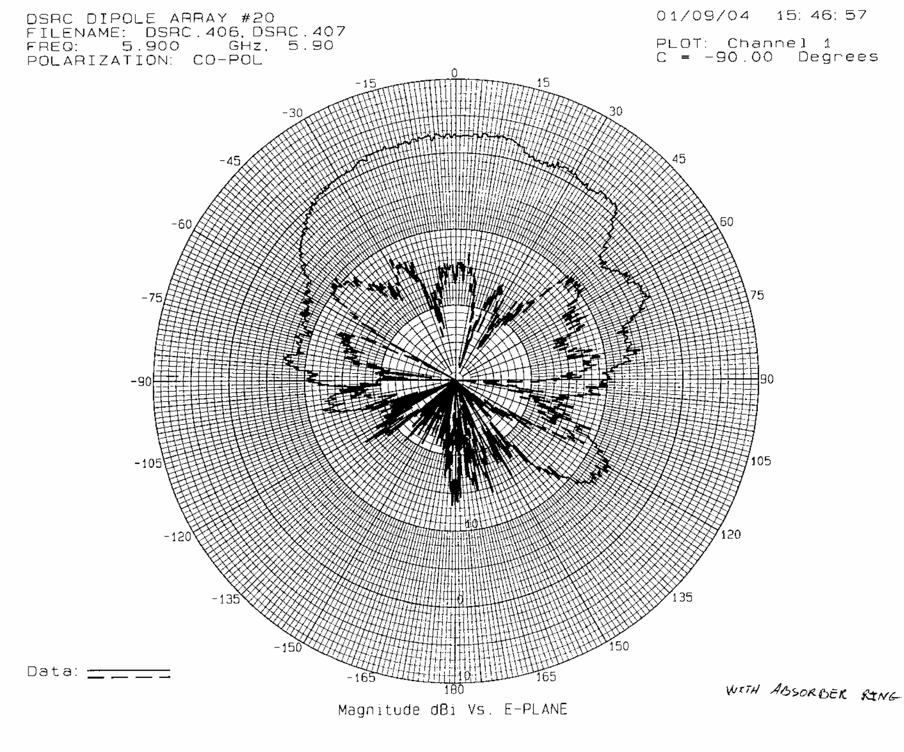


Figure 3-B. Elevation Radiation Pattern of the Mirror Mount Antenna Including 2dB Cable Loss

3.2.1.2 Gain – 5/8 Wave Roof Mount Antenna

The roof mount antenna including its radome and 2-foot long coaxial pigtail were placed on a 3-foot diameter rolled-edge ground plane in the anechoic chamber. The vertically polarized antenna gain was measured at a frequency of 5.888GHz. Because the 2-foot coaxial pigtail is an integral part of the antenna, the measured gain includes the 2dB loss of the coaxial pigtail. The azimuth gain pattern shown in Figure 37 was measured by rotating the antenna on its vertical axis. The elevation pattern shown in Figure 38 was measured by rotating the antenna along the horizontal.

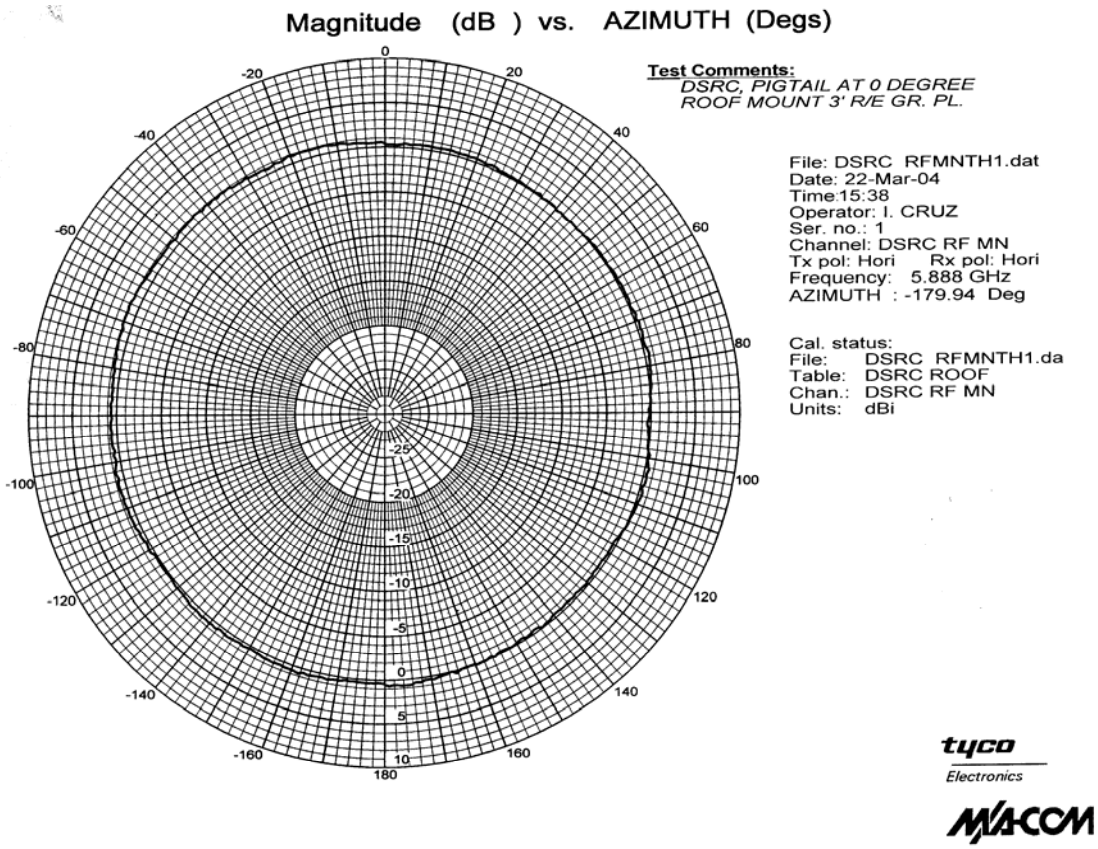


Figure 3-C. Azimuth Radiation Pattern of the Roof Mount Antenna Including 2dB Cable Loss

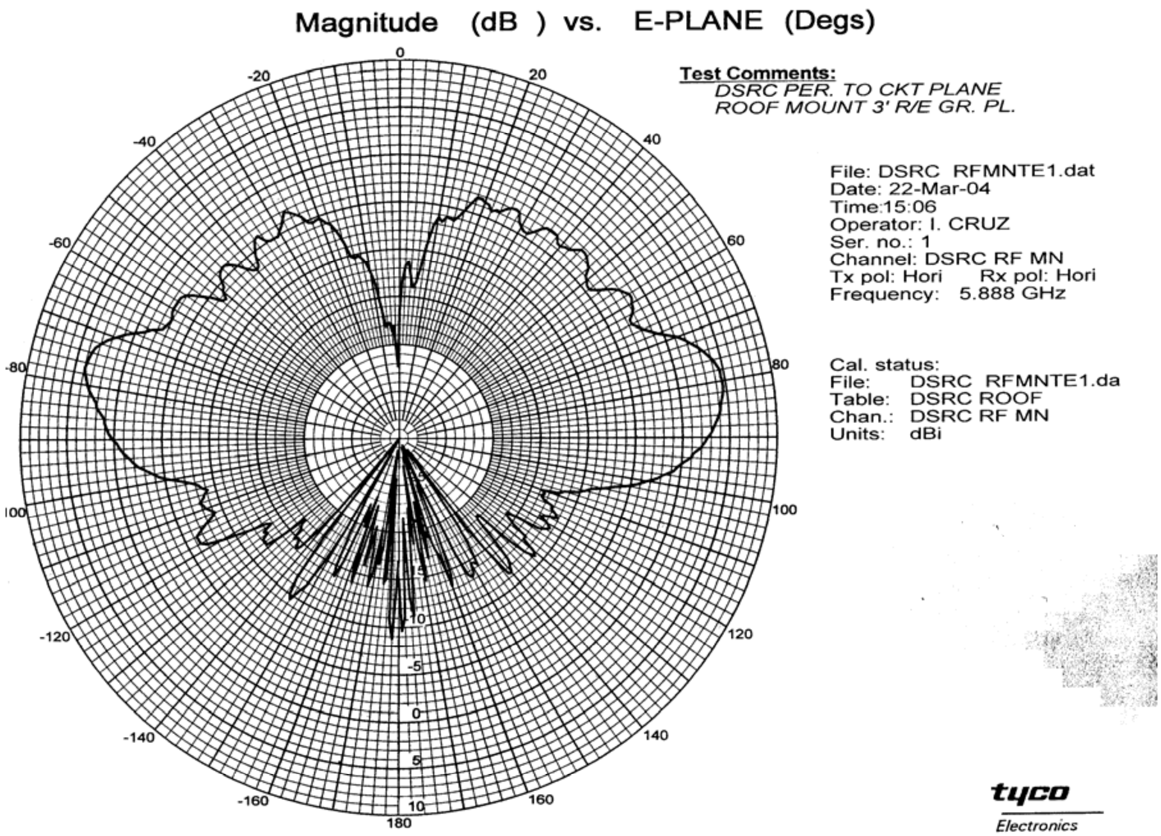


Figure 3-D. Elevation Radiation Pattern of the Roof Mount Antenna Including 2dB Cable Loss

3.2.1.3 Gain – 4-Element WLAN Roof Mount Antenna

Prior to the start of this subproject, CAMP-VSCC used a WLAN Access Point antenna with the VSC test kits to investigate approximate performance of DSRC systems. To understand how the antennas described above perform with respect to the WLAN antenna, base performance characteristic measurements needed to be taken in the same fashion.

The 4-element roof mount antenna including 3 meters of LMR-195 coaxial cable was placed on a 3-foot diameter rolled-edge ground plane in the anechoic chamber. The vertically polarized antenna gain was measured at a frequency of 5.2GHz. Because the 3-meter coaxial pigtail is an integral part of the antenna, the measured gain includes the 3dB loss of the coaxial pigtail. The azimuth gain pattern shown in Figure 39 was measured by rotating the antenna on its vertical axis. The elevation pattern shown in Figure 38 was measured by rotating the antenna along the horizontal.

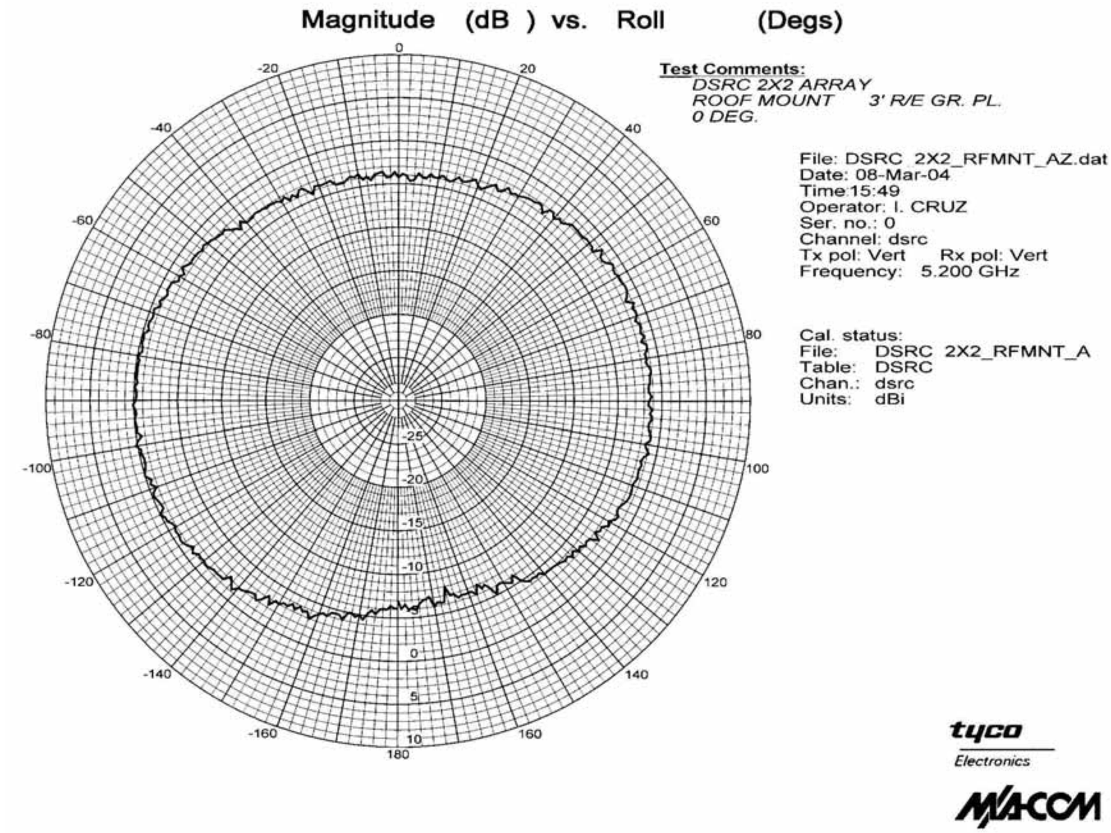


Figure 3-E. Azimuth Radiation Pattern of the Roof Mount Antenna Including 3dB Cable Loss

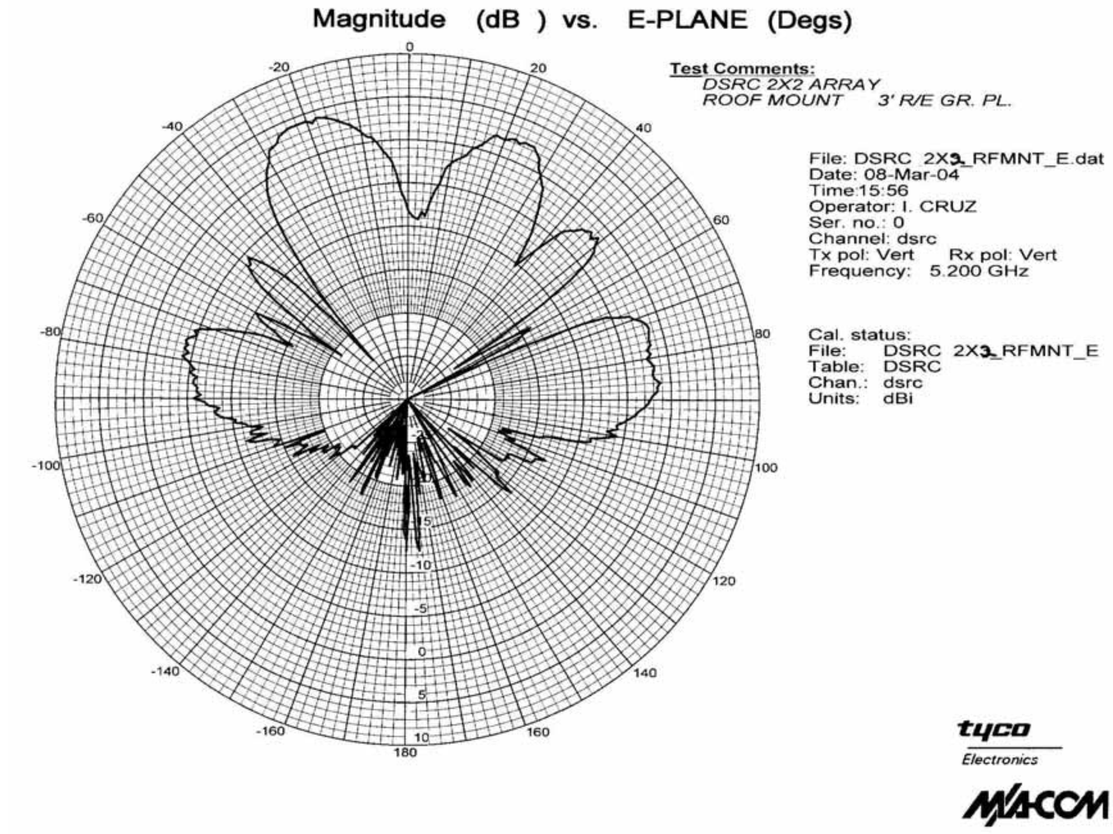


Figure 3-F. Azimuth Radiation Pattern of the Roof Mount Antenna Including 3dB Cable Loss

3.2.2 Bench Test

The Voltage Standing Wave Ratio (VSWR) measurements were conducted on each style antenna at JEF Consultant Inc. in Belleville, MI. using an HP 8753C vector network analyzer having time domain capabilities. The measurements were performed using time domain gating to eliminate the effects of the 2-foot coaxial pigtail.

3.2.2.1 VSWR – Side-View Mirror

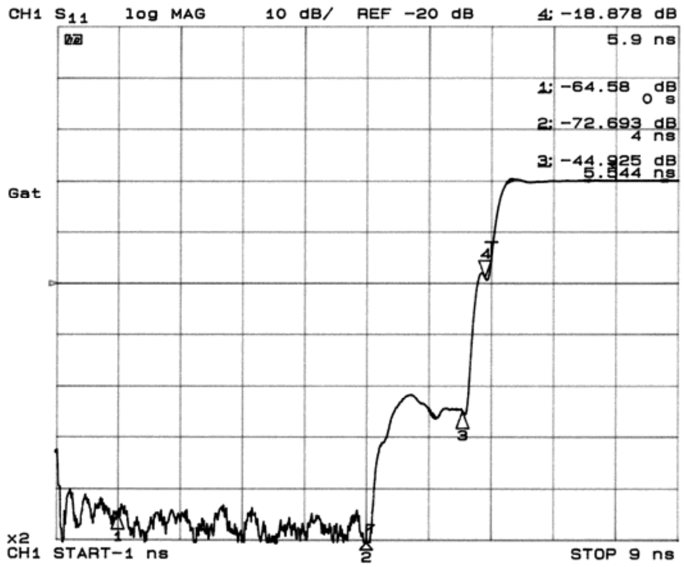


Figure 3-G. Time Domain Trace Showing Gate Window Showing Two-Way Propagation Time.

The gate was centered at 4ns with a width of 4ns

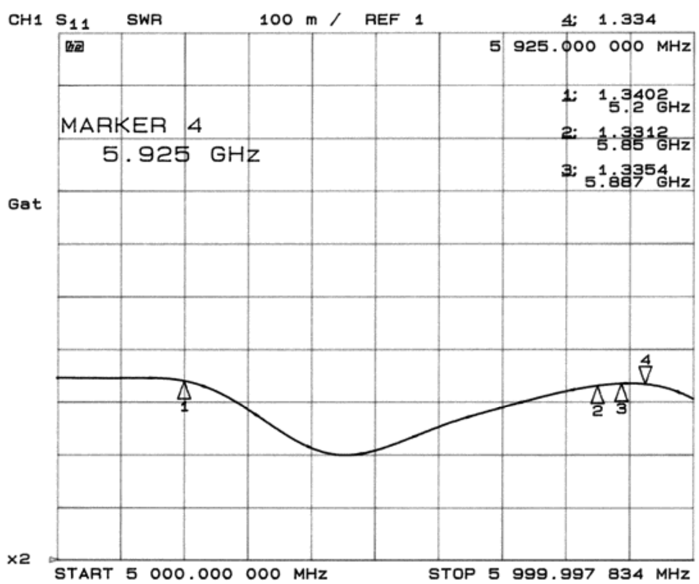


Figure 3-H. Measured VSWR

3.2.2.2 VSWR – Roof Mount

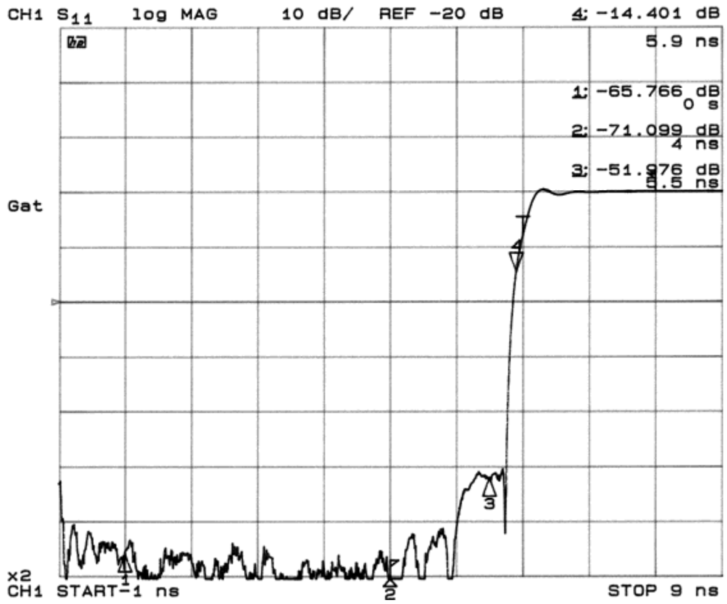


Figure 3-I. Time Domain Trace Showing Gate Window Showing Two-Way Propagation Time.

The gate was centered at 4ns with a width of 4ns.

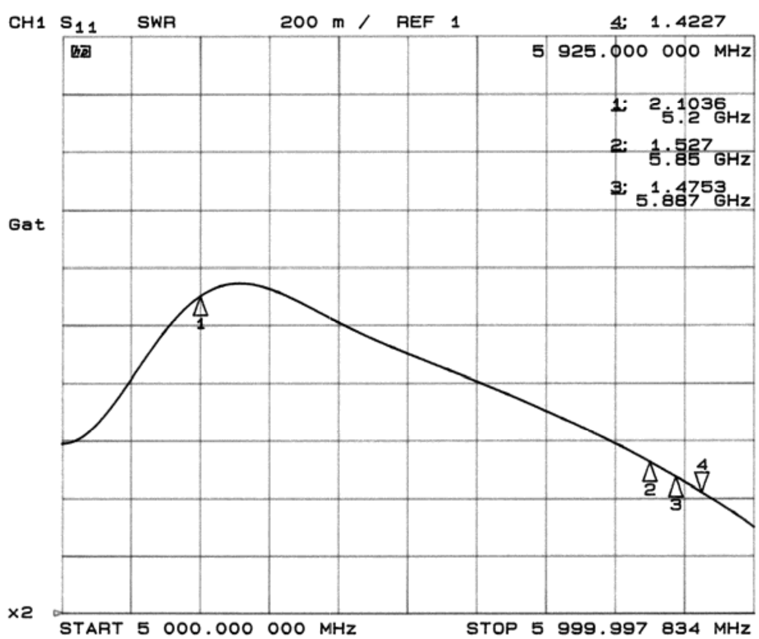


Figure 3-J. Measured VSWR

3.2.3 Summary

The measured gain of mirror mount antenna shows good agreement with the predicted performance as stated in the simulation report. The ripples in the azimuth radiation pattern in Figure 35 are due in part to the fixture suspending the antenna in free space and the housing. The antenna does provide good gain and nearly uniform coverage over ±90° azimuth. The elevation pattern shown in Figure 36 also shows good elevation coverage to ±30°.

The measured VSWR of the mirror mount antenna shown in Figure 42 is also in agreement with the simulation. The VSWR is nearly flat at approximately 1.3:1 over the entire frequency range of interest including the WLAN and ITS DSRC bands.

The roof mount antenna is not as broad banded as the mirror mount design as shown in Figure 44. The VSWR in the ITS DSRC band is approximately 1.4:1 and 2.1:1 in the WLAN band.

3.3 Vehicle Level Range testing

3.3.1 J.E.F. Range Characteristics

Vehicle level radiation pattern data was taken at the JEF antenna range. The antenna range utilizes a 40-foot turntable with a conductive surface. The large turntable allows a vehicle to be offset so as to align the rotation axis with the antenna under test. This greatly reduces rotation eccentricity thereby reducing or eliminating measured gain fluctuations due to both path loss variation and source beam width effects. The antenna range uses low loss Andrew ½" Helix coaxial cable and a rotary joint at the turntable.

The measurements were conducted using a Agilent E8742C synthesized signal generator, Hughes Instruments 8020H02 traveling wave tube amplifier, an HP 8593A spectrum analyzer, and two standard gain horns. With this equipment, a 70dB test dynamic range was achieved.

A standard gain horn was used as the source antenna and was located 7 meters (32 feet) from the turntable center. The height of the source standard was adjusted to the antenna under test (AUT) height prior to measurements.

Calibration Setup

Calibration was performed using two gain standard horns of known gains for the frequencies tested. Images of the calibration setup are shown in Figures 45 and 46. The horns are spaced at 23 feet at a height of 48". Calibrations were performed at 5.2, 5.85, 5.8875, and 5.925GHz.

Figure 3-K. Calibration Setup

Figure 3-L. Calibration Setup

3.3.2 Side-Mirror Antenna Tests

Below are various images taken of the range configuration for testing the mirror mount antenna on both driver and passenger sides of the vehicle.

Antenna Height of 45”

Unavoidable Offset From Source

Antenna Aligned With Turntable Rotation Axis

Driver-Side Mirror Setup

Vehicle With Respect to Horn Source

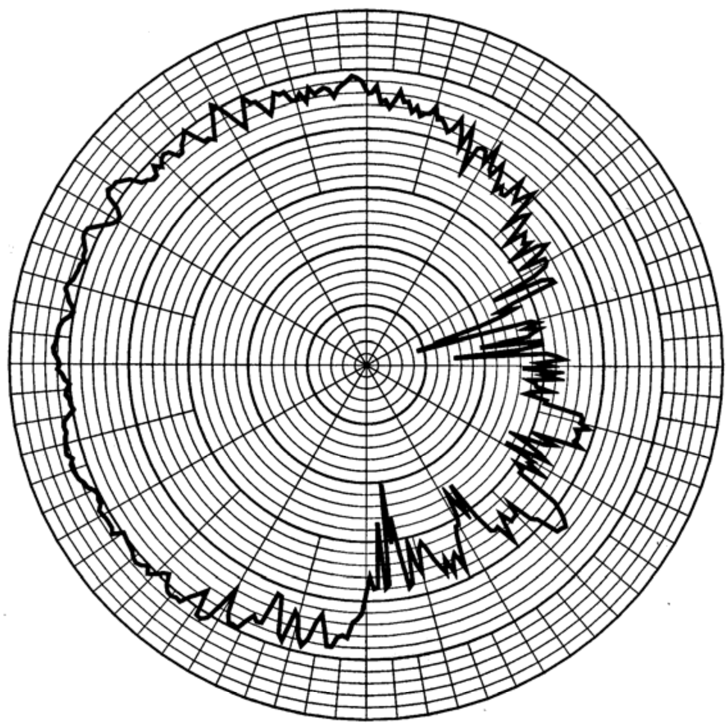
Passenger-Side Mirror Setup

3.3.2.1 Driver Side-Mirror Pattern (Unit 26) 5850 MHz

JEF CONSULTANT INC.

DATE.....02-25-2004 · TIME.....11:04:17 PATTERN.....004

REF = 10 dBi
2 dB/DIV



AVERAGE GAIN.......-2.9 dBi
MIN/MAX RATIO...... 43.8 dB

MAX GAIN........... 2.7 dBi
MIN GAIN...........-41.1 dBi

UNIT TESTED....2002 INFINITI
Mfg./Model.....Q45
Type...........MIRROR MOUNT ANTENNA
Comments.......UNIT 26

Frequency......5.85 GHz
ID Number......2Q4515
Location.......DRIVER SIDE MIRROR

RF DETECTOR....SPECTRUM ANALYZER
Resolution BW..30 KHz

Mfg./Model.....HP 8593E
Detector Fn....Peak

RF SOURCE......LAB SIGNAL
RF Level.......-10 dBm
Transmit Ant...NRL STD GAIN HORN
Height.........45 INCHES

Mfg./Model.....AGILENT E8247C
Modulation.....NONE
Polarization...VERTICAL
Range..........23 FT.

Software bv JEF Consultant. Inc. (734) 482-5505

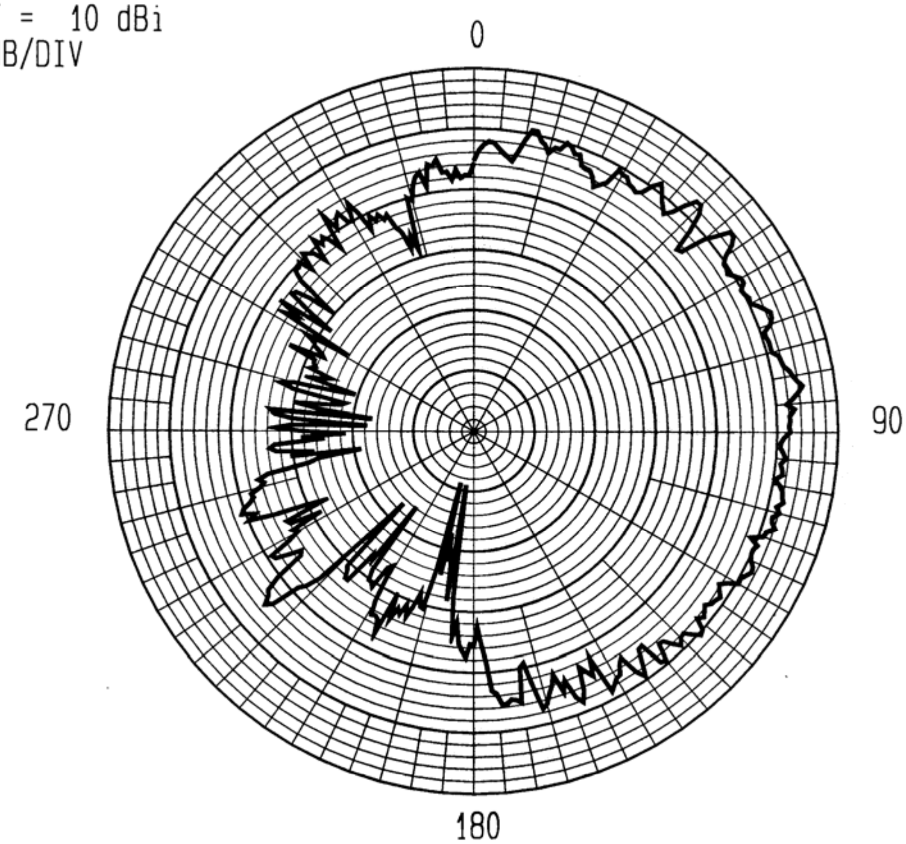
Figure 3-M. Mirror Mount Antenna Including 2 ft Pigtail (2dB Loss)

3.3.2.2 Passenger Side-Mirror Pattern (Unit 26) 5850 MHz

JEF CONSULTANT INC.

DATE.....02-25-2004 . TIME.....17:32:59 PATTERN.....023

REF = 10 dBi
2 dB/DIV



AVERAGE GAIN.......-3.1 dBi
MIN/MAX RATIO...... 45.8 dB

MAX GAIN........... 4.6 dBi
MIN GAIN...........-41.1 dBi

UNIT TESTED....2002 INFINITI
Mfg./Model.....Q45
Type...........MIRROR MOUNT ANTENNA
Comments.......UNIT 26

Frequency......5.85 GHz
ID Number......2Q4515
Location.......PASSENGER MIRROR

RF DETECTOR....SPECTRUM ANALYZER
Resolution BW..30 KHz

Mfg./Model.....HP 8593E
Detector Fn....Peak

RF SOURCE......LAB SIGNAL
RF Level.......-10 dBm
Transmit Ant...NRL STD GAIN HORN
Height.........45 INCHES

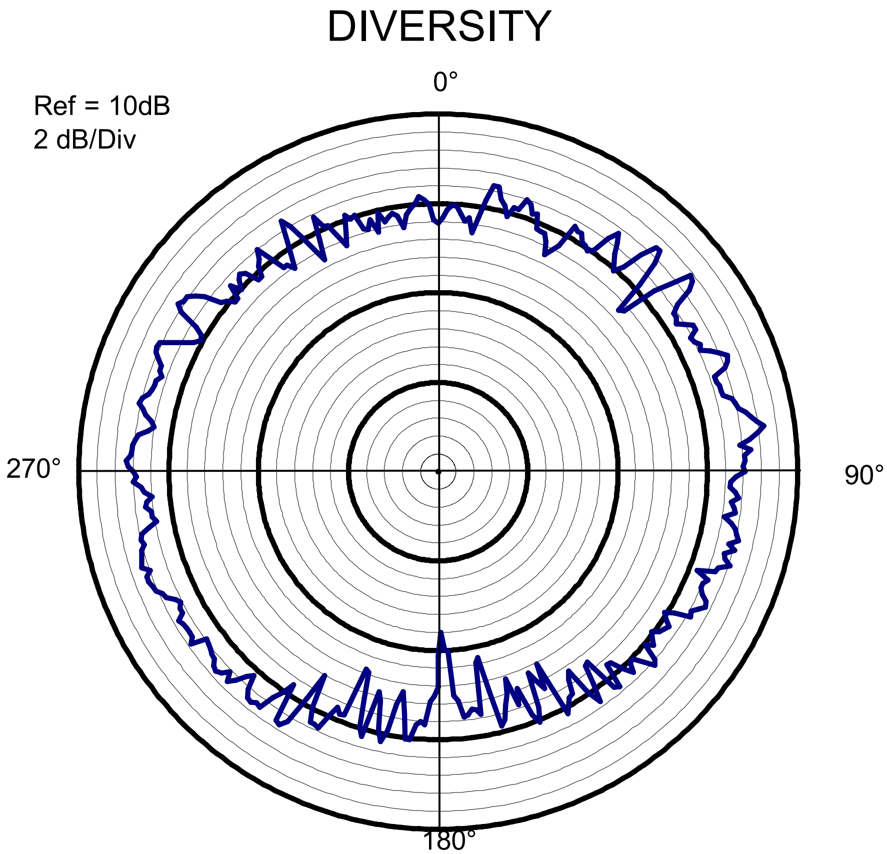
Mfg./Model.....AGILENT E8247C
Modulation.....NONE
Polarization...VERTICAL
Range..........23 FT.

Software bv JEF Consultant. Inc. (734) 482-5505

Figure 3-N. Mirror Mount Antenna Including 2 ft Pigtail (2dB Loss)

3.3.2.3 Side Mirror Composite Diversity Pattern (Unit 26) 5850 MHz

Combining the driver- and passenger-side mirror radiation patterns in Figures 47 and 48 respectively can create a simulated diversity pattern. Figure 49 was created by comparing point-by-point the driver and passenger side mirror antenna data and keeping the greater amplitude. There exists a null rear of the vehicle; otherwise the coverage is nearly uniform.



Statistics		**5.85 GHz**			
Average	1.73	dBil	Maximum	6.63	dBil
Std Dev	2.90	dBil	Minimum	-12.02	dBil
			Max-Min	18.65	dBil

Antenna 1	UNIT 26	DRIVER SIDE MIRROR
Antenna 2	UNIT 26	PASSENGER MIRROR

Figure 3-O. Composite Radiation Pattern

3.3.3 Roof Mount Antenna Tests on Ground Plane

The roof mount antennas were placed on a 36-inch diameter aluminum ground plane located 45 inches above the turntable.

4-Element WLAN Antenna on Ground Plane

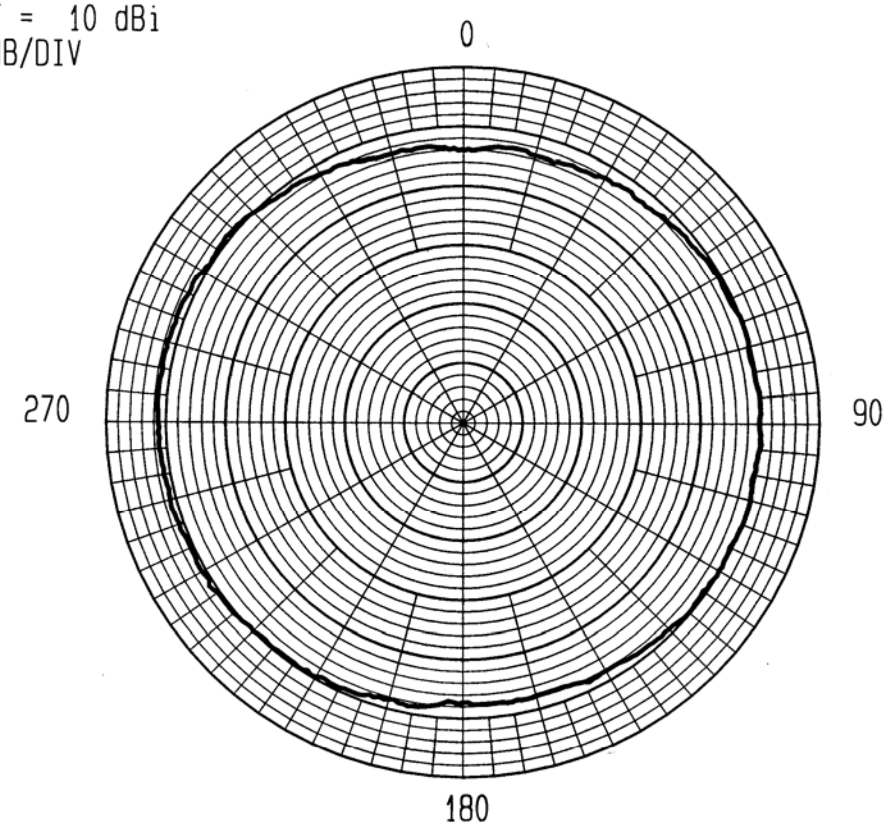
5/8 Wave Antenna on Ground Plane

3.3.3.1 4-Element Array 5200MHz

JEF CONSULTANT INC.

DATE.....03-18-2004 .   TIME.....10: 48: 44   PATTERN.....004

REF = 10 dBi
2 dB/DIV



AVERAGE GAIN.......-.7 dBi
MIN/MAX RATIO...... 5.6 dB

MAX GAIN........... 1.5 dBi
MIN GAIN...........-4.1 dBi

UNIT TESTED....3 FT. DIA. GROUND PL
Mfg./Model.....N/A
Type...........4 ELEMENT ARRAY
Comments.......WITH 9 FT. LMR-195 COAX

Frequency......5200 MHz
ID Number......N/A
Location.......CENTER OF TURNTABLE

RF DETECTOR....SPECTRUM ANALYZER
Resolution BW..30 KHz

Mfg./Model.....HP 8593E
Detector Fn....Peak

RF SOURCE......LAB SIGNAL
RF Level.......-10 dBm
Transmit Ant...NRL STD GAIN HORN
Height.........45.5 INCHES

Mfg./Model.....AGILENT E8247C
Modulation.....NONE
Polarization...VERTICAL
Range..........23 FT.

Software by JEF Consultant Inc. (734) 482-5505

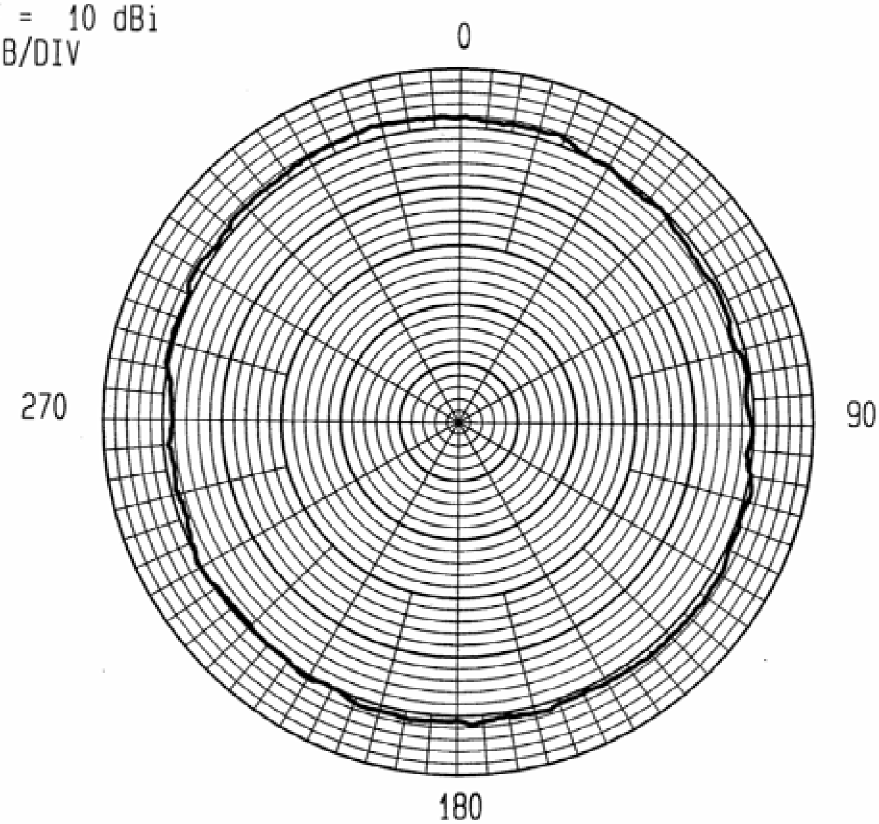
Figure 3-P. 4-Element WLAN Antenna Performance on Ground Plane Including 3dB Cable Loss

3.3.3.2 5/8 Wave 5887.5MHz

JEF CONSULTANT INC.

DATE.....03-18-2004   TIME.....10: 21: 48   PATTERN.....002

REF = 10 dBi
2 dB/DIV



AVERAGE GAIN....... .5 dBi
MIN/MAX RATIO...... 4 dB

MAX GAIN........... 2.2 dBi
MIN GAIN...........-1.8 dBi

UNIT TESTED....3 FT. DIA. GROUND PL
Mfg./Model.....N/A
Type...........5/8 WAVE ROOF MOUNT
Comments.......2 FEET PIGTAIL

Frequency......5887.5 MHz
ID Number......N/A
Location.......CENTER OF TURNTABLE

RF DETECTOR....SPECTRUM ANALYZER
Resolution BW..30 KHz

Mfg./Model.....HP 8593E
Detector Fn....Peak

RF SOURCE......LAB SIGNAL
RF Level.......-10 dBm
Transmit Ant...NRL STD GAIN HORN
Height.........45.5 INCHES

Mfg./Model.....AGILENT E8247C
Modulation.....NONE
Polarization...VERTICAL
Range..........23 FT.

Software by JEF Consultant. Inc. (734) 482-5505

Figure 3-Q. 5/8 Wave Antenna Performance on Ground Plane Including 2dB Cable Loss

3.3.4 Roof Mount Antenna Test on Vehicle With Sunroof

The images below show the range configuration for testing the roof mount antennas on a vehicle with a sunroof. Both the 5/8 wave and 4-element WLAN antennas were located approximately 6 inches rearward of the sunroof.

Roof Mount Antenna

View From Source Antenna

Cable Route and Alignment

AUT Rotation on Turntable Axis

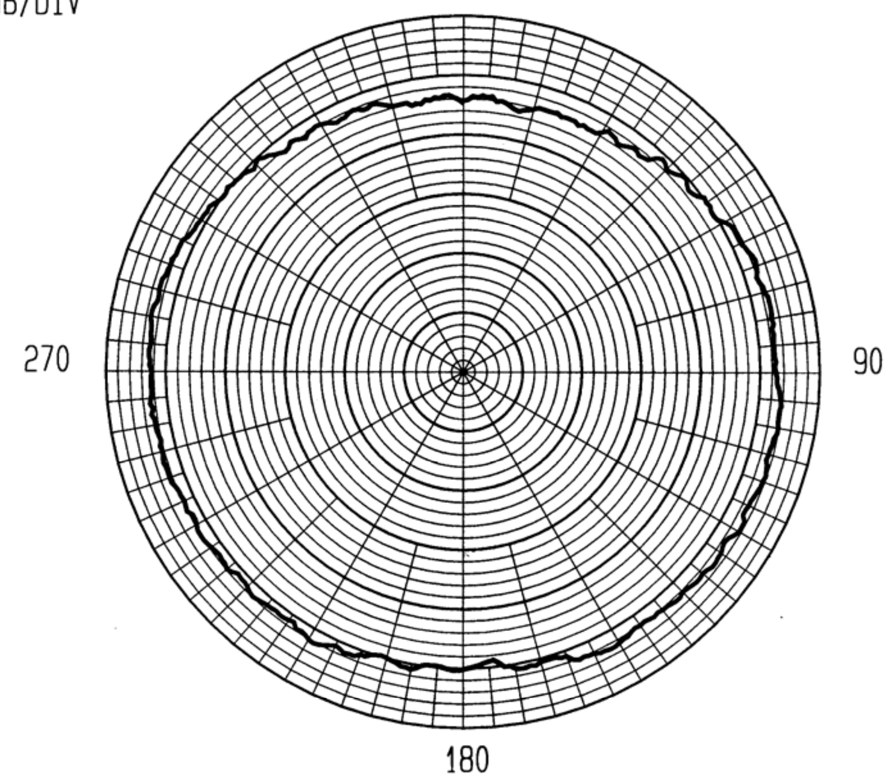
3.3.4.1 4-Element Array 5200MHz

JEF CONSULTANT INC.

DATE.....03-04-2004 . TIME.....11:13:53 PATTERN.....002

REF = 10 dBi
2 dB/DIV

0



AVERAGE GAIN....... 1.1 dBi
MIN/MAX RATIO...... 8.9 dB

MAX GAIN........... 3.8 dBi
MIN GAIN...........-5.1 dBi

UNIT TESTED....2002 INFINITI
Mfg./Model.....Q45
Type...........4-ELEMENT ARRAY
Comments.......WITH 9 FT. LMR-195 COAX

Frequency......5200 MHz
ID Number......2Q4515
Location.......CENTER OF ROOF

RF DETECTOR....SPECTRUM ANALYZER
Resolution BW..30 KHz

Mfg./Model.....HP 8593E
Detector Fn....Peak

RF SOURCE......LAB SIGNAL
RF Level.......-10 dBm
Transmit Ant...NRL STD GAIN HORN
Height.........58 INCHES

Mfg./Model.....AGILENT E8247C
Modulation.....NONE
Polarization...VERTICAL
Range..........23 FT.

Software by JEF Consultant, Inc. (734) 482-5505

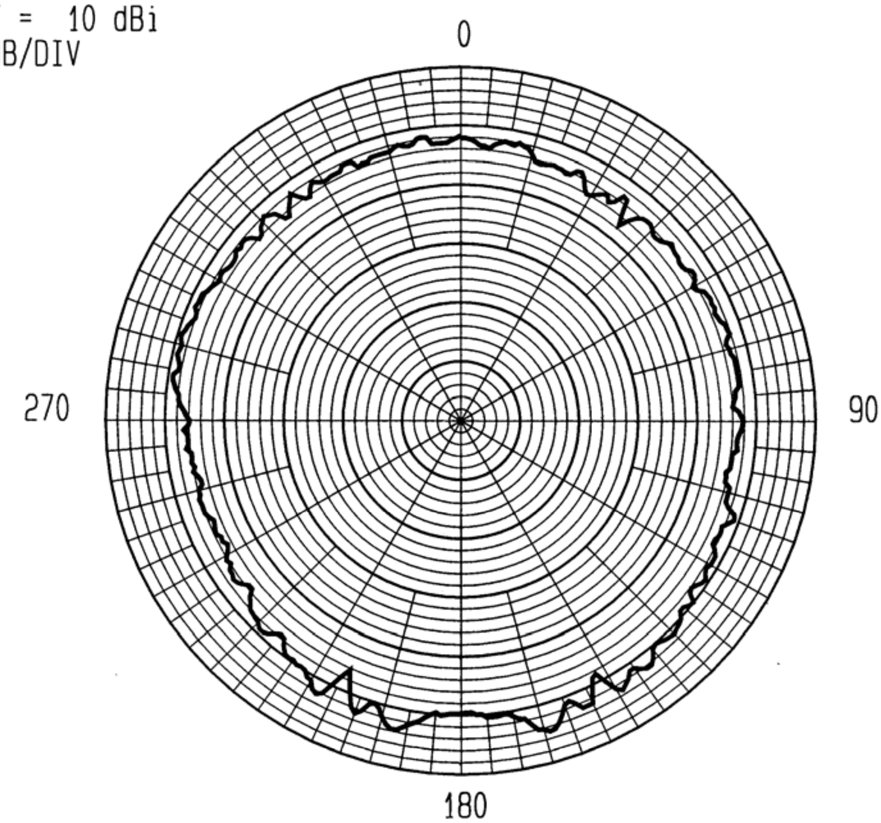
Figure 3-R. 4-Element Array With Sunroof Including 3dB Cable Loss

3.3.4.2 5/8 Roof Mount 5850MHz

JEF CONSULTANT INC.

DATE.....03-04-2004 . TIME.....11: 24: 05 PATTERN.....003

REF = 10 dBi
2 dB/DIV



AVERAGE GAIN.......-1.4 dBi	MAX GAIN........... 4.8 dBi
MIN/MAX RATIO...... 12.2 dB	MIN GAIN...........-7.4 dBi
UNIT TESTED....2002 INFINITI	Frequency......5850 MHz
Mfg./Model.....Q45	ID Number......2Q4515
Type...........5/8 WAVE ROOF MOUNT	Location.......CENTER OF ROOF
Comments.......2 FEET PIGTAIL	
RF DETECTOR....SPECTRUM ANALYZER	Mfg./Model.....HP 8593E
Resolution BW..30 KHz	Detector Fn....Peak
RF SOURCE......LAB SIGNAL	Mfg./Model.....AGILENT E8247C
RF Level.......-10 dBm	Modulation.....NONE
Transmit Ant...NRL STD GAIN HORN	Polarization...VERTICAL
Height.........58 INCHES	Range..........23 FT.

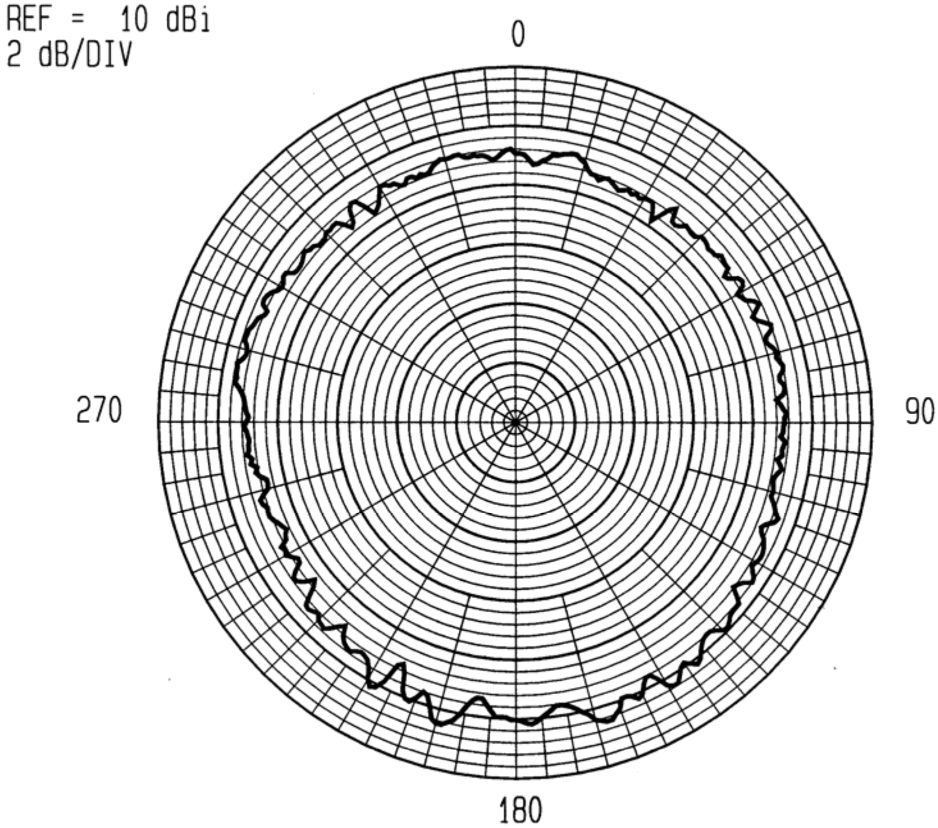
Software bv JEF Consultant. Inc. (734) 482-5505

Figure 3-S. 5/8 Wave With Sunroof Including 2dB Cable Loss

3.3.4.3 5/8 Roof Mount 5887.5MHz

JEF CONSULTANT INC.

DATE.....03-04-2004 . TIME.....11:39:30 PATTERN.....004



AVERAGE GAIN.......-3.2 dBi
MIN/MAX RATIO...... 11.7 dB

MAX GAIN........... 2.6 dBi
MIN GAIN...........-9 dBi

UNIT TESTED....2002 INFINITI
Mfg./Model.....Q45
Type...........5/8 WAVE ROOF MOUNT
Comments.......2 FEET PIGTAIL

Frequency......5887.5 MHz
ID Number......2Q4515
Location.......CENTER OF ROOF

RF DETECTOR....SPECTRUM ANALYZER
Resolution BW..30 KHz

Mfg./Model.....HP 8593E
Detector Fn....Peak

RF SOURCE......LAB SIGNAL
RF Level.......-10 dBm
Transmit Ant...NRL STD GAIN HORN
Height.........58 INCHES

Mfg./Model.....AGILENT E8247C
Modulation.....NONE
Polarization...VERTICAL
Range..........23 FT.

Software by JEF Consultant. Inc. (734) 482-5505

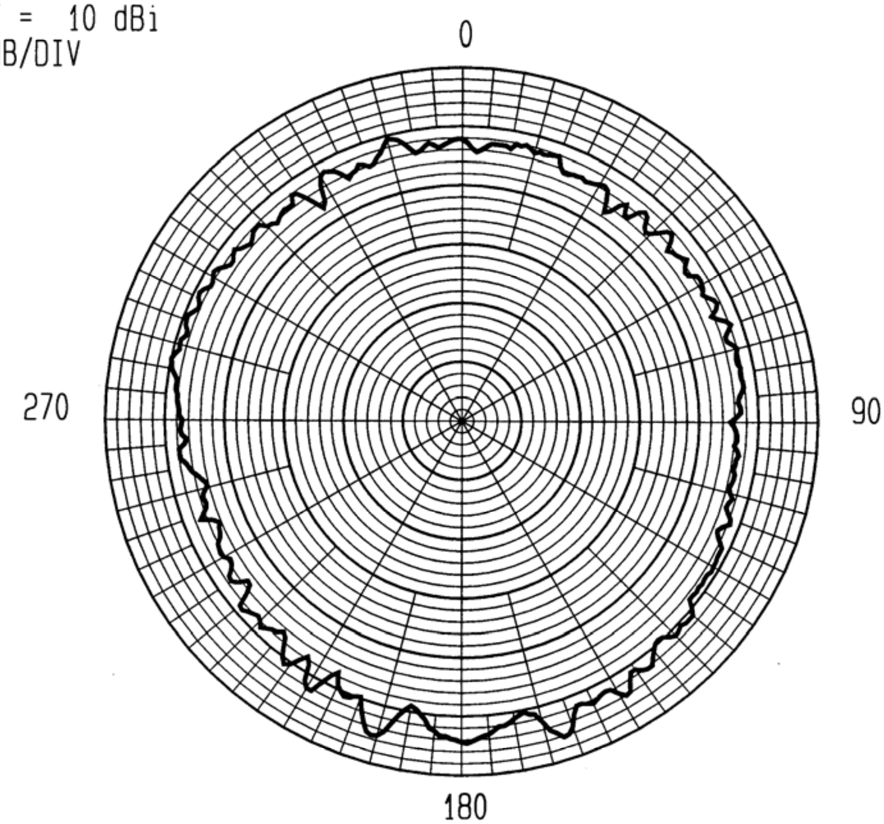
Figure 3-T. 5/8 Wave With Sunroof Including 2B Cable Loss

3.3.4.4 5/8 Roof Mount 5925MHz

JEF CONSULTANT INC.

DATE.....03-04-2004 . TIME.....11: 48: 25 PATTERN.....005

REF = 10 dBi
2 dB/DIV



AVERAGE GAIN.......-1 dBi	MAX GAIN........... 6.1 dBi
MIN/MAX RATIO...... 13.4 dB	MIN GAIN...........-7.3 dBi
UNIT TESTED....2002 INFINITI	Frequency......5925 MHz
Mfg./Model.....Q45	ID Number......2Q4515
Type...........5/8 WAVE ROOF MOUNT	Location.......CENTER OF ROOF
Comments.......2 FEET PIGTAIL	
RF DETECTOR....SPECTRUM ANALYZER	Mfg./Model.....HP 8593E
Resolution BW..30 KHz	Detector Fn....Peak
RF SOURCE......LAB SIGNAL	Mfg./Model.....AGILENT E8247C
RF Level.......-10 dBm	Modulation.....NONE
Transmit Ant...NRL STD GAIN HORN	Polarization...VERTICAL
Height.........58 INCHES	Range..........23 FT.

Software bv JEF Consultant. Inc. (734) 482-5505

Figure 3-U. 5/8 Wave With Sunroof Including 2dB Cable Loss

3.3.5 Roof Mount Antenna Tests on Vehicle Without Sunroof

Side View of WLAN Antenna on Vehicle

Side View of 5/8 Wave Antenna on Vehicle

Rear View of WLAN Antenna on Vehicle

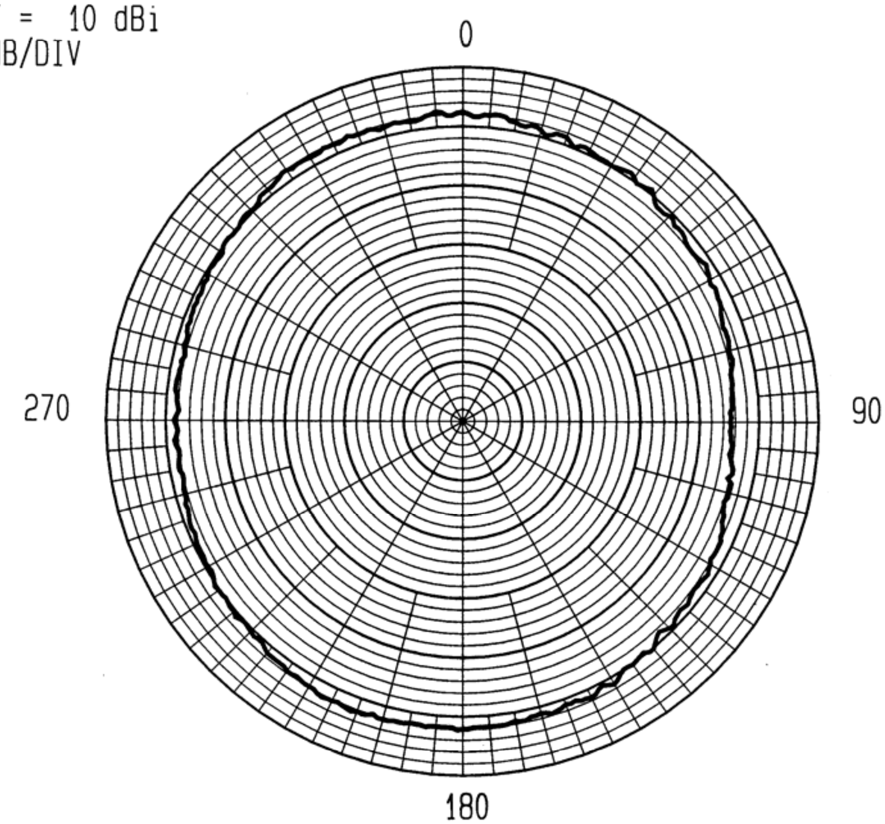
Rear View of 5/8 Wave Antenna on Vehicle

3.3.5.1 4-Element Array 5200MHz

JEF CONSULTANT INC.

DATE.....03-18-2004 .   TIME.....11:33:11   PATTERN.....005

REF = 10 dBi
2 dB/DIV



AVERAGE GAIN....... .1 dBi
MIN/MAX RATIO...... 7.5 dB

MAX GAIN........... 2.6 dBi
MIN GAIN...........-4.9 dBi

UNIT TESTED....'99 MERCEDES
Mfg./Model.....E320
Type...........4 ELEMENT ARRAY
Comments.......WITH 9 FT. LMR-195 COAX

Frequency......5200 MHz
ID Number......OWNED BY M/A-COM
Location.......CENTER OF ROOF

RF DETECTOR....SPECTRUM ANALYZER
Resolution BW..30 KHz

Mfg./Model.....HP 8593E
Detector Fn....Peak

RF SOURCE......LAB SIGNAL
RF Level.......-10 dBm
Transmit Ant...NRL STD GAIN HORN
Height.........56.5 INCHES

Mfg./Model.....AGILENT E8247C
Modulation.....NONE
Polarization...VERTICAL
Range..........23 FT.

Software bv JEF Consultant. Inc. (734) 482-5505

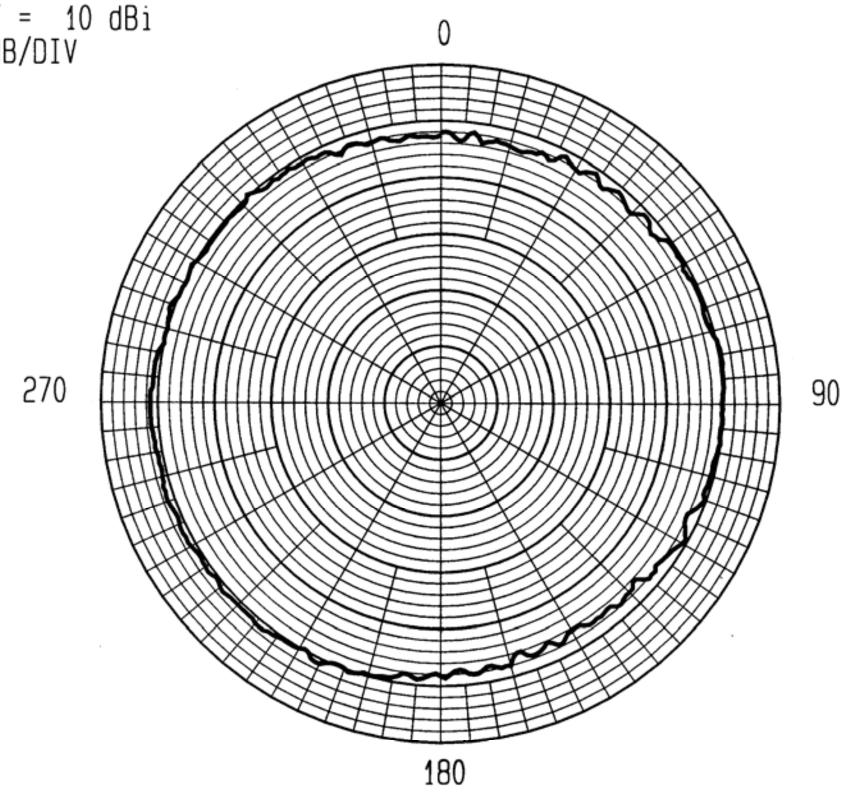
Figure 3-V. 4-Element Array Without Sunroof Including 3dB Cable Loss

3.3.5.2 5/8 Wave 5850MHz

JEF CONSULTANT INC.

DATE.....03-18-2004 .   TIME.....12: 55: 47   PATTERN.....011

REF = 10 dBi
2 dB/DIV



AVERAGE GAIN.......-.7 dBi
MIN/MAX RATIO...... 5.2 dB

MAX GAIN........... 1.3 dBi
MIN GAIN...........-3.9 dBi

UNIT TESTED....'99 MERCEDES
Mfg./Model.....E320
Type...........5/8 WAVE ROOF MOUNT
Comments.......WITH 2 FT. PIG TAIL

Frequency......5258 MHz
ID Number......OWNED BY M/A-COM
Location.......CENTER OF ROOF

RF DETECTOR....SPECTRUM ANALYZER
Resolution BW..30 KHz

Mfg./Model.....HP 8593E
Detector Fn....Peak

RF SOURCE......LAB SIGNAL
RF Level.......-10 dBm
Transmit Ant...NRL STD GAIN HORN
Height.........56.5 INCHES

Mfg./Model.....AGILENT E8247C
Modulation.....NONE
Polarization...VERTICAL
Range..........23 FT.

Software bv JEF Consultant. Inc. (734) 482-5505

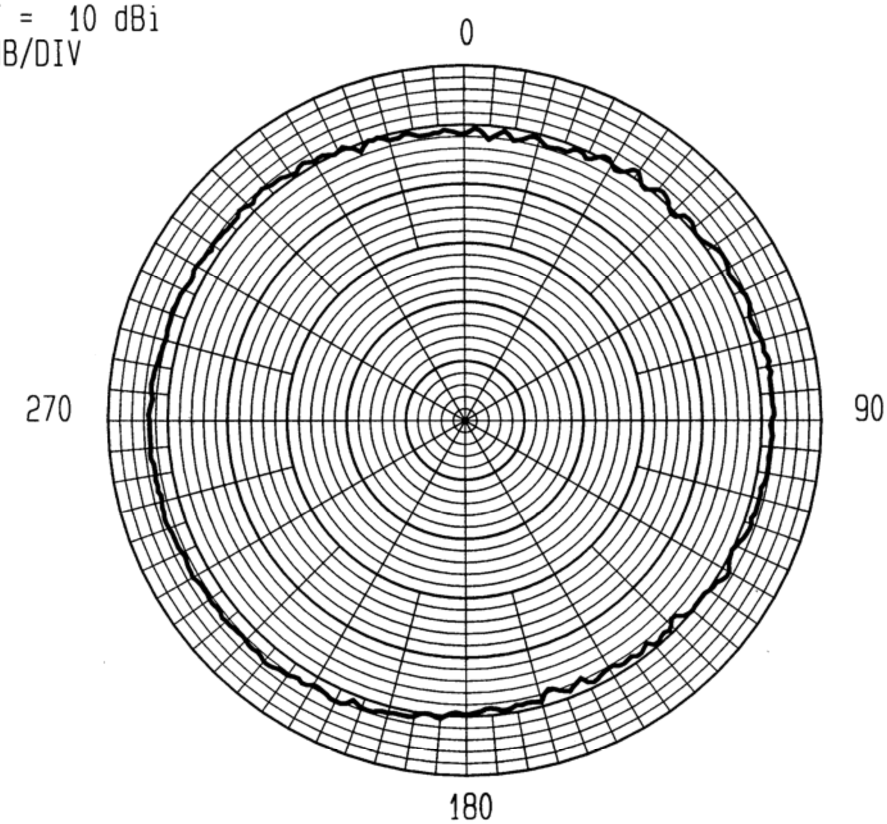
Figure 3-W. 5/8 Wave Without Sunroof Including 2dB Cable Loss

3.3.5.3 5/8 Wave 5887.5MHz

JEF CONSULTANT INC.

DATE.....03-18-2004 TIME.....12: 46: 30 PATTERN.....010

REF = 10 dBi
2 dB/DIV



AVERAGE GAIN....... 1.1 dBi
MIN/MAX RATIO...... 5.8 dB

MAX GAIN........... 3.2 dBi
MIN GAIN...........-2.6 dBi

UNIT TESTED....'99 MERCEDES
Mfg./Model.....E320
Type...........5/8 WAVE ROOF MOUNT
Comments.......WITH 2 FT. PIG TAIL

Frequency......5887.5 MHz
ID Number......OWNED BY M/A-COM
Location.......CENTER OF ROOF

RF DETECTOR....SPECTRUM ANALYZER
Resolution BW..30 KHz

Mfg./Model.....HP 8593E
Detector Fn....Peak

RF SOURCE......LAB SIGNAL
RF Level.......-10 dBm
Transmit Ant...NRL STD GAIN HORN
Height.........56.5 INCHES

Mfg./Model.....AGILENT E8247C
Modulation.....NONE
Polarization...VERTICAL
Range..........23 FT.

Software by JEF Consultant. Inc. (734) 482-5505

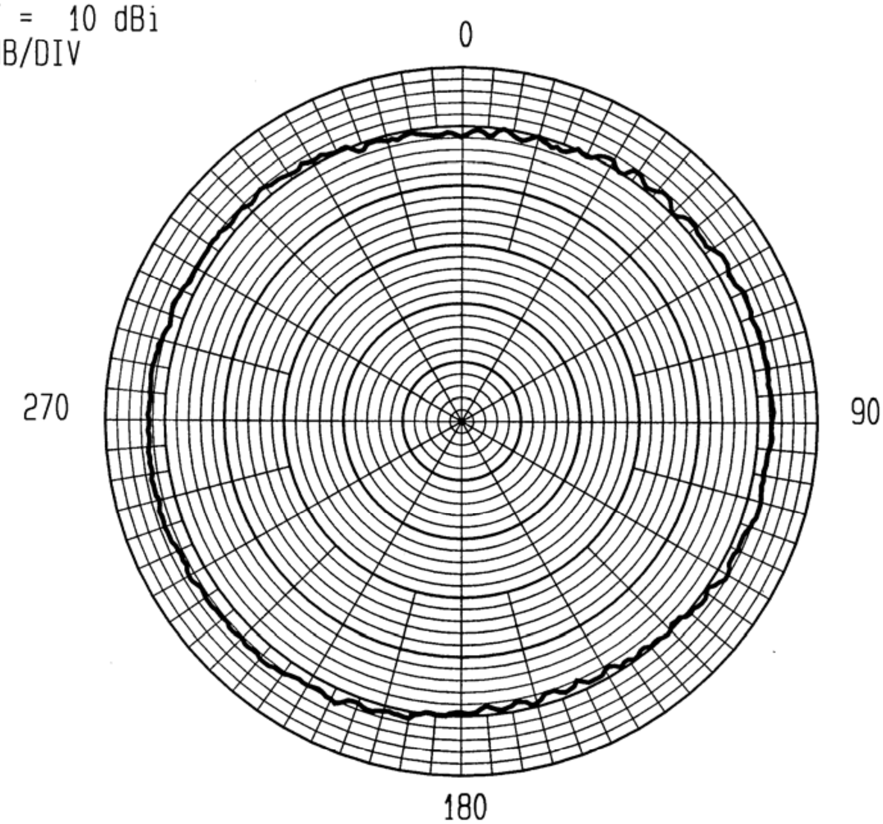
Figure 3-X. 5/8 Wave Without Sunroof Including 2dB Cable Loss

3.3.5.4 5/8 Wave 5925MHz

JEF CONSULTANT INC.

DATE.....03-18-2004 TIME.....13: 06: 21 PATTERN.....012

REF = 10 dBi
2 dB/DIV



AVERAGE GAIN....... 1.3 dBi
MIN/MAX RATIO...... 5.2 dB

MAX GAIN........... 3.2 dBi
MIN GAIN...........-2 dBi

UNIT TESTED....'99 MERCEDES
Mfg./Model.....E320
Type...........5/8 WAVE ROOF MOUNT
Comments.......WITH 2 FT. PIG TAIL

Frequency......5925 MHz
ID Number......OWNED BY M/A-COM
Location.......CENTER OF ROOF

RF DETECTOR....SPECTRUM ANALYZER
Resolution BW..30 KHz

Mfg./Model.....HP 8593E
Detector Fn....Peak

RF SOURCE......LAB SIGNAL
RF Level.......-10 dBm
Transmit Ant...NRL STD GAIN HORN
Height.........56.5 INCHES

Mfg./Model.....AGILENT E8247C
Modulation.....NONE
Polarization...VERTICAL
Range..........23 FT.

Software bv JEF Consultant. Inc. (734) 482-5505

Figure 3-Y. 5/8 Wave Without Sunroof Including 2dB Cable Loss

3.4 Summary

3.4.1 Side Mirror Antenna

The measured vehicle level performance of the side mirror antenna shows no unexpected results having minimal vehicle influence. Each location provides good pattern coverage and gain for the respective driver and passenger sides of the vehicle. The simulated diversity combination of both patterns indicate nearly uniform azimuth coverage 360° around the vehicle and, in some cases, would provide better reception given diversity's ability to overcome physical obstacles realized by only one antenna.

3.4.2 Roof Mount

Both the 5/8 wave and a 4-element WLAN roof mount antennas were tested on a 36" diameter ground plane, a vehicle with a sunroof, and a vehicle without a sunroof. These measurements are intended to compare the vehicle and sunroof effects on antenna performance as compared to performance on a ground plane. The 4-element WLAN antenna serves as a reference antenna that was used in earlier drive testing conducted in the WLAN frequency band.

A comparison of the 5/8 wave and 4-element WLAN antennas operating at their center design frequency is shown below in Table 1.

	Avg gain, dBil, corrected for cable loss		
	36" GP	With sun roof	Without sun roof
4 element WLAN @ 5.2 GHz	2.3	4.1	3.1
5/8 wave @ 5.8875 GHz	2.5	-1.2	3.1

Table 1 Comparison of 5/8 Wave and WLAN Reference Antennas.

As shown Table 1, the antennas compare well on both the ground plane and vehicle without a sunroof however the 5/8 wave is more impacted by the presence of the sunroof. Both antennas exhibited gain bias to the vehicle rear and front to back gain variations of 4dB due to the sunroof as shown in Figures 52 and 54.

3.5 Test Kit Measurements

The test kits were evaluated for output frequency and transmit power at the JEF facility. This measurement was conducted using an HP 8593A spectrum analyzer as shown in Figure 60.

Figure 3-Z. Test Kit Evaluation Setup

The spectrum analyzer was set to a wide frequency span and max hold trace function. The test kit was configured to send 3000 packets of 4096 bytes per packet. The trace peak is then measured using a marker set to the desired frequency and the power level is read in dBm. The cable loss of 1.25dB is added back and the result is converted to mW.

The results of these tests are shown in Tables 1 and 2.

Logged in as root		**Power, mW**	
F (MHz)	**F measured**	**100%**	**25%**
5200	5200	47.3, 42.9	15.8
5800	5800	45.7, 45.9	
5900	5900	24.4	
5990	5990	16.8	

Logged in as DSRC		
F (MHz)	**F measured**	**100%**
5200	5320	57.8
5900	5320	62.7

Table 1. Test Kit Data Taken on January 30, 2004

	100%		50%	
F (MHz)	dBm raw	mW converted	dBm raw	mW converted
5150	9.65	12.3	6.21	5.6
5350	10.05	13.5	6.9	6.5
5850	8.45	9.3	6.8	6.4
5890	9.56	12	7.48	7.5
5925	9.25	11.2	6.12	5.5

Table 2. Test Kit Data Taken on February 9, 2004

The inconsistency of the transmit power did not appear to be associated with the revision level of the software or output port selected.

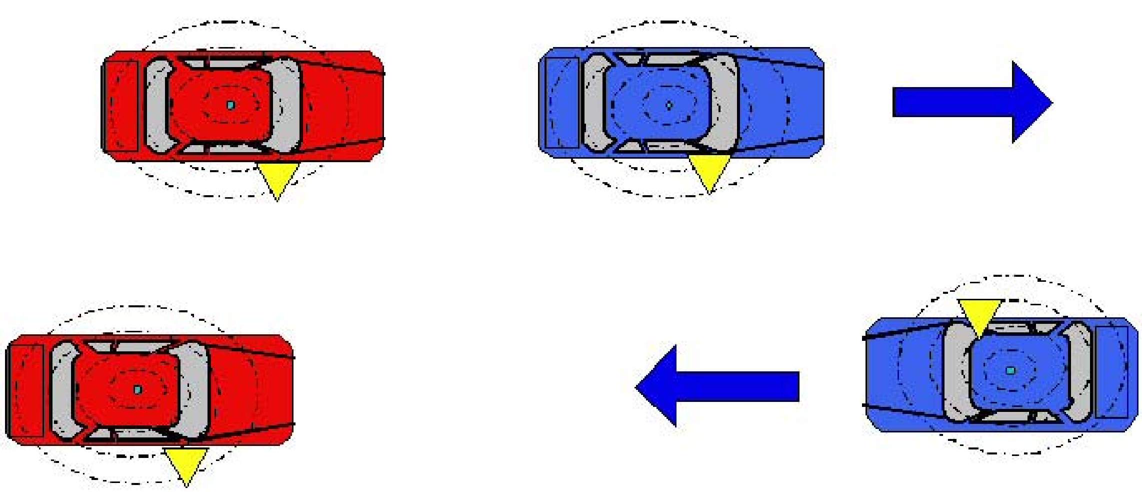
3.6 Drive Testing

Sections 3.6.1 through 3.6.5 define various drive test vehicle configurations. In all cases, the receiving vehicle is stationary and depicted in red. The transmitting vehicle is depicted in blue and the arrow indicates its direction of travel. The yellow triangle indicates the location of the side view mirror antenna; the roof mount is not indicated and is located in the center of the roof.

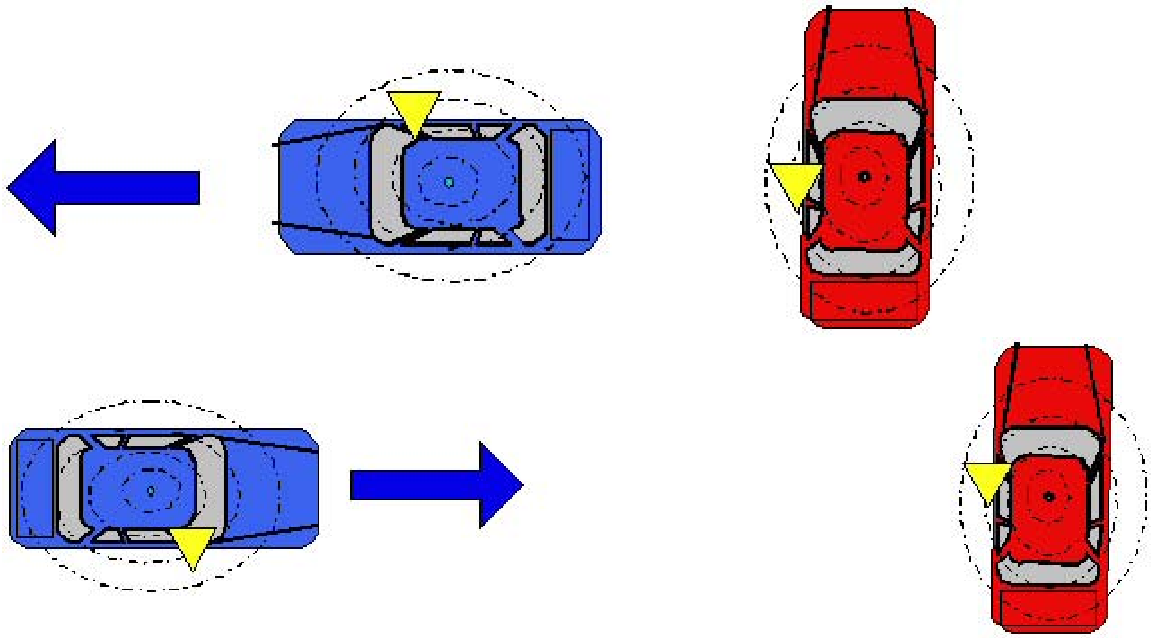
Drive tests were conducted at the Ford Motor Co. Dearborn Proving Ground, General Motors Milford Proving Ground (MPG), and a residential side street using test kits provided by CAMP. The collected data was processed through M/A-COM developed software to facilitate graphing and propagation modeling.

Drive tests conducted at the Ford Proving Ground are similar to those conducted at GM MPG, however the extension cables were not used at Ford due to connecter issues. Because the added cable losses are not in the system, the performance is 4dB better and so these results are listed at the end of Appendix D.

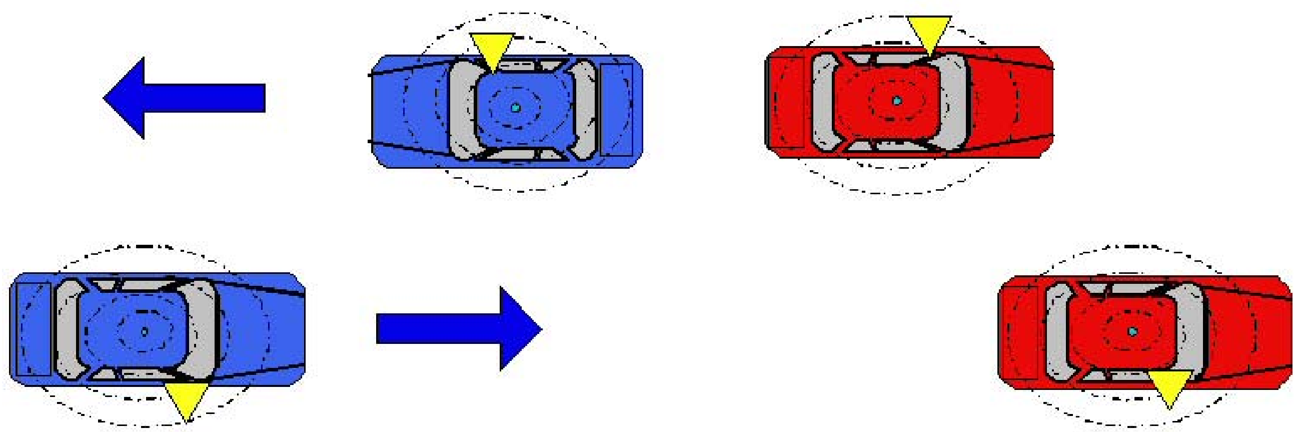
3.6.1 Receiving Vehicle Front



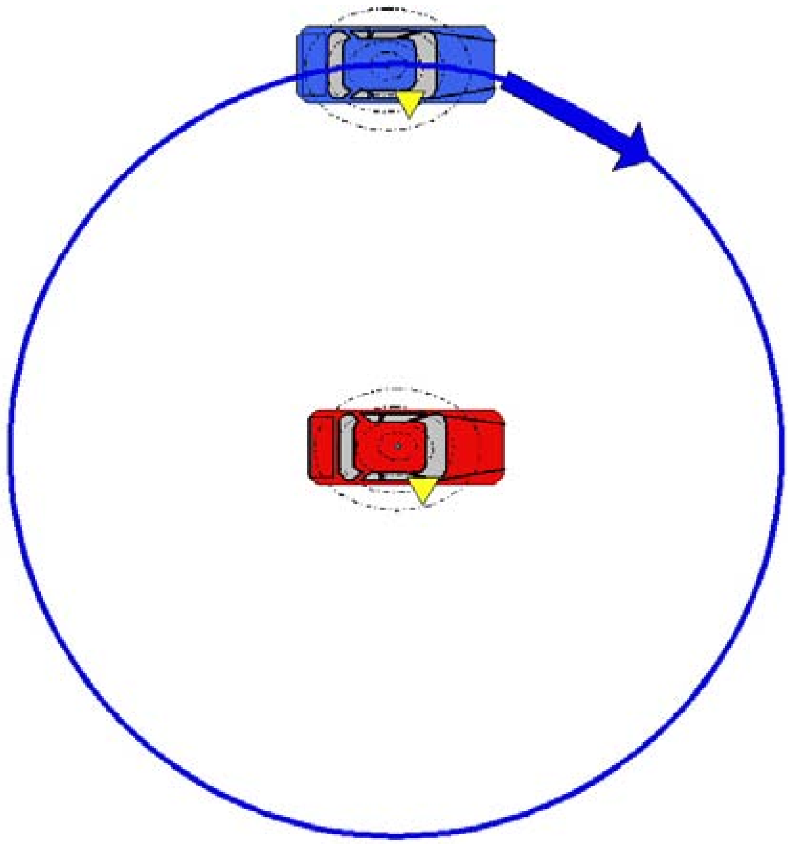
3.6.2 Receiving Vehicle Broadside



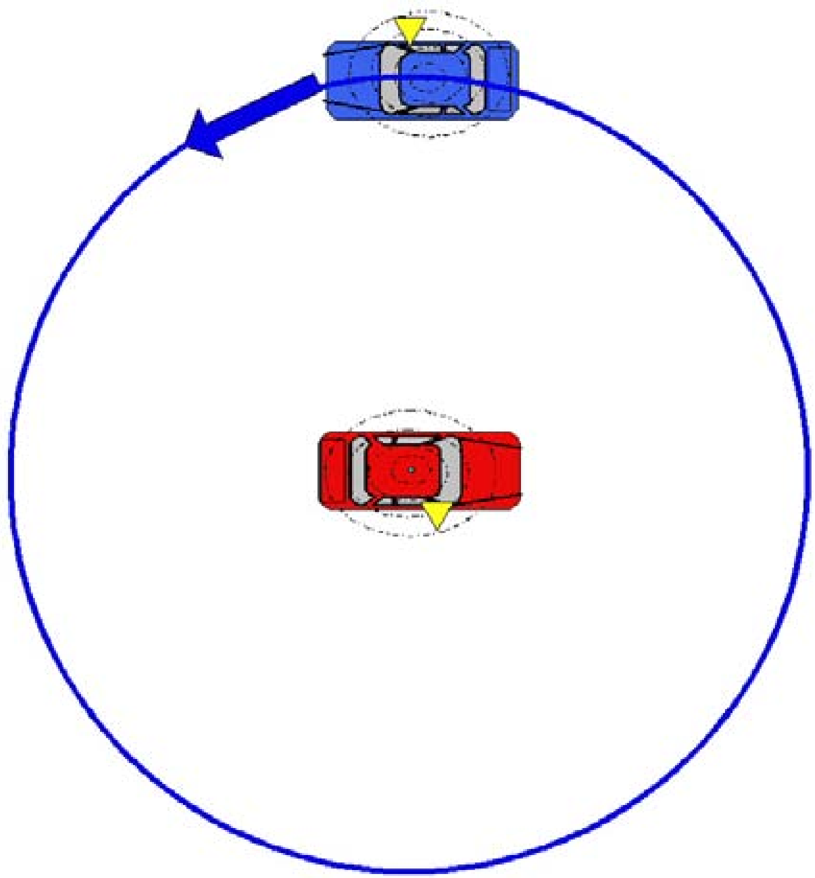
3.6.3 Receiving Vehicle Rear



3.6.4 Clockwise Circular Passenger-Side Antenna



3.6.5 Counter-Clockwise Circular Passenger-Side Antenna

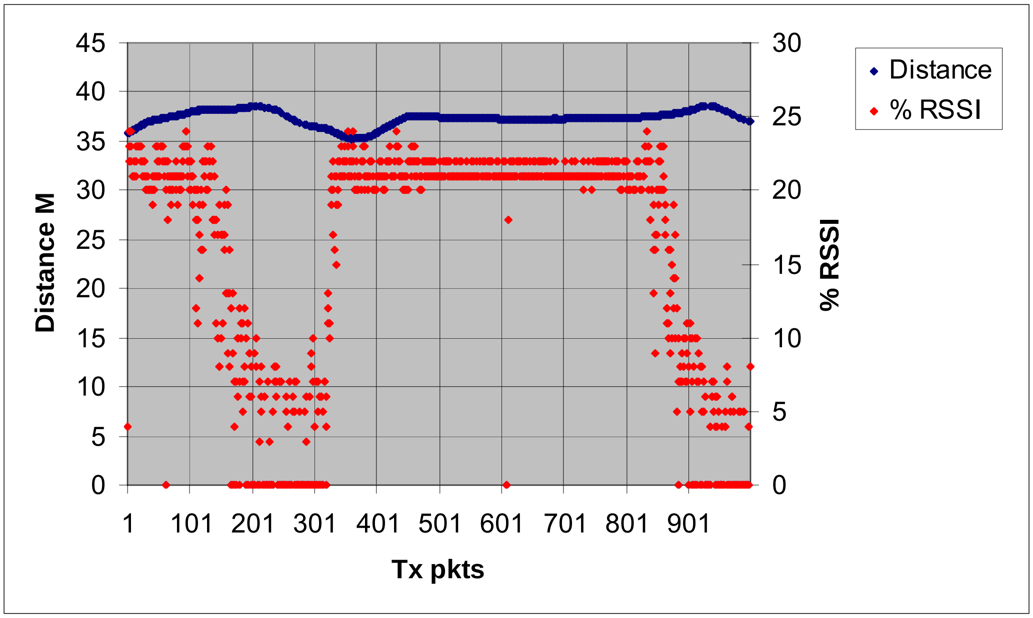


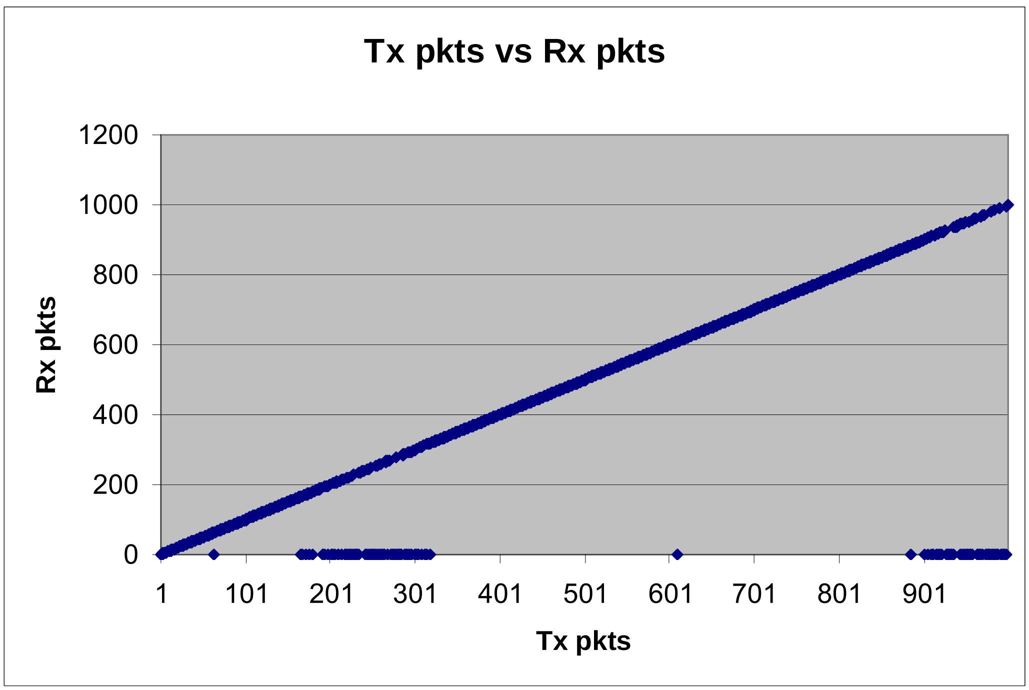
3.6.6 Test Results – Mirror Mount General Motors Proving Ground

Drive testing using both mirror mount antennas was conducted at the General Motors Milford Proving Ground. The intent for this testing was to measure the effective communication range of the mirror mount antennas under diversity conditions. The antenna pigtails are connected to the test kits using 6-foot long production intent extension coaxial cables made of LMR-195 having a measured 2dB of loss.

It was later discovered, during GM 12 test, that the auxiliary input port of the receiver test kit associated with the passenger side of the receiving vehicle was significantly less sensitive than the main port. As a result, the diversity measurements are not valid and explain why some packets were dropped during the initial grist mill track testing.

3.6.6.1 GM 1 5890 Clockwise Circular Passenger-Side Antenna

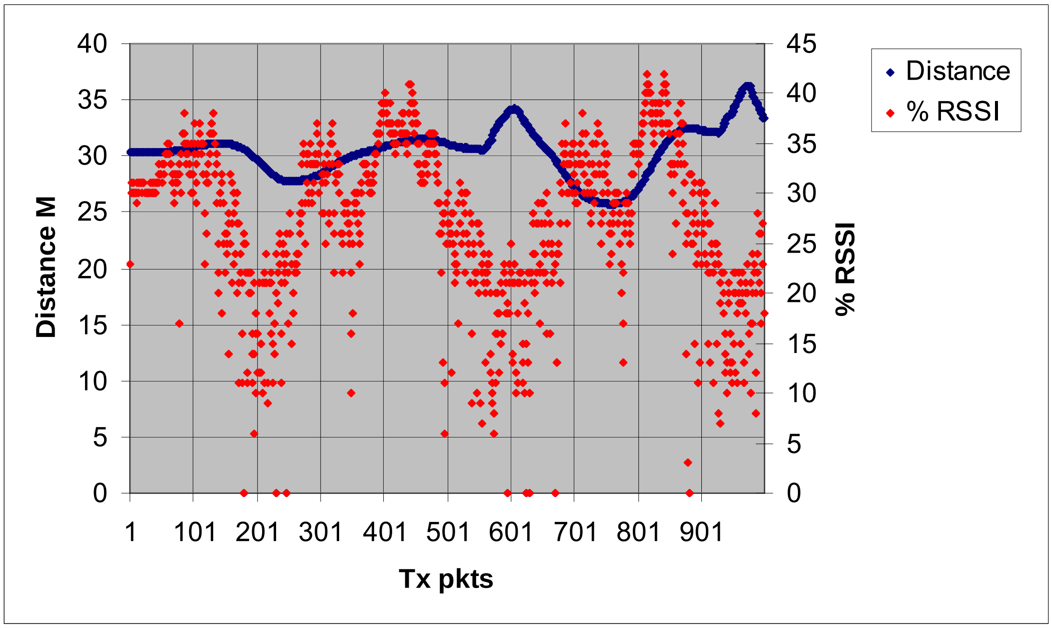


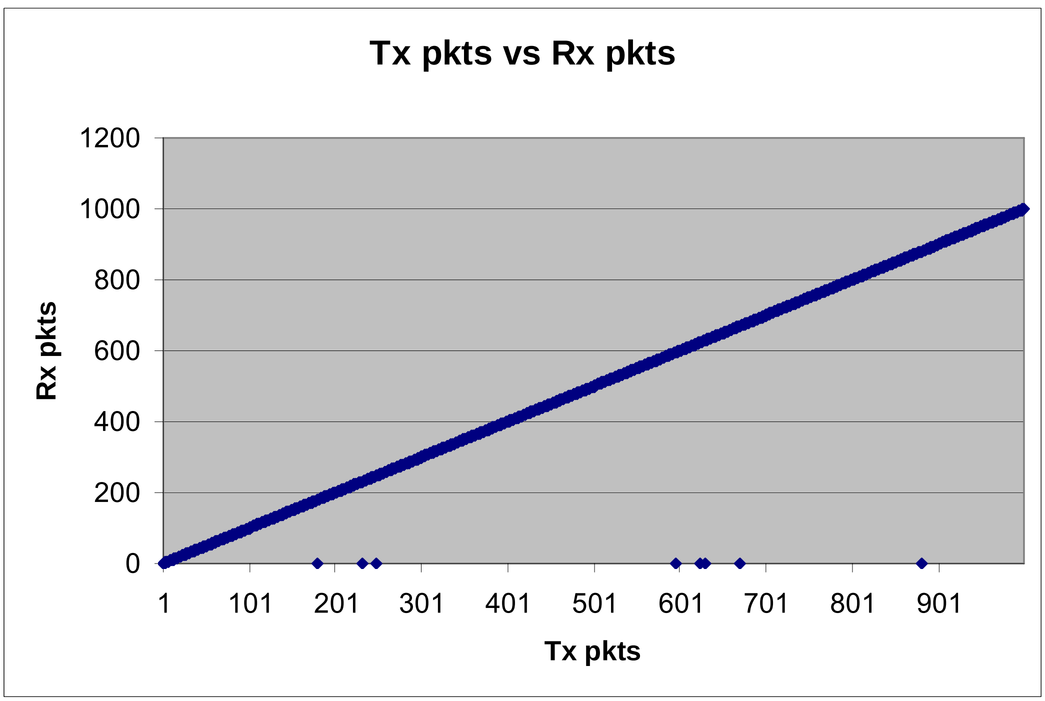


Total packets sent: 999

Total packets dropped: 134

3.6.6.2 GM 3 5890 Clockwise Circular Passenger-Side Antenna

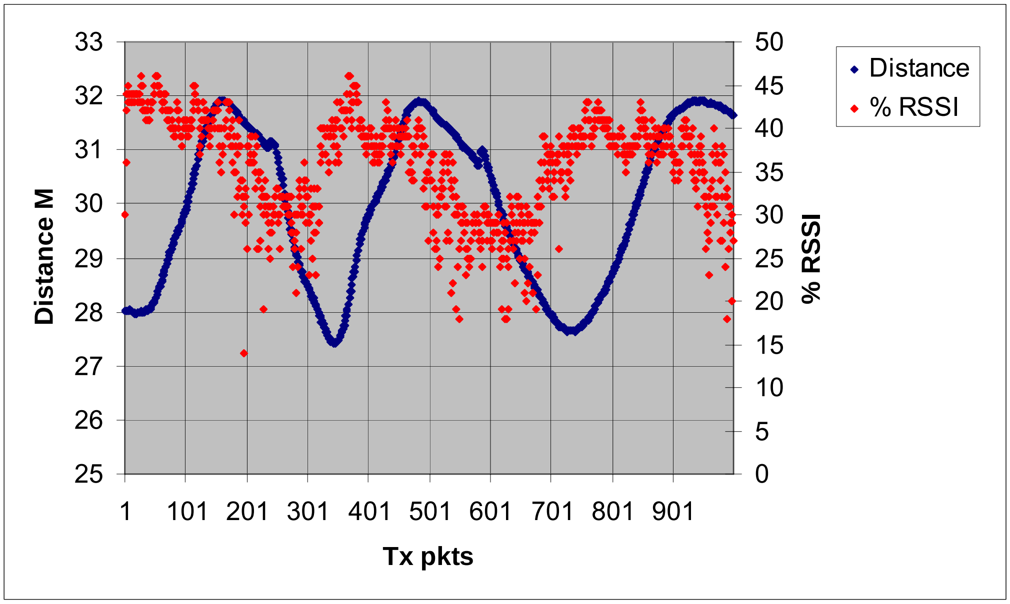


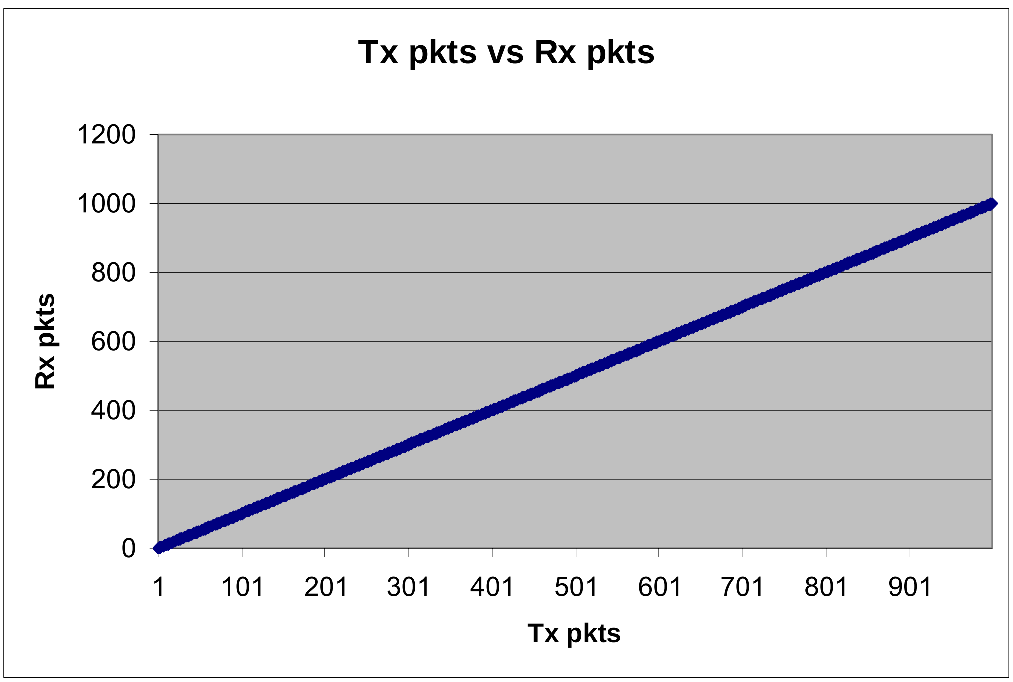


Total packets sent: 999

Total packets dropped: 8

3.6.6.3 GM 4 5200 Clockwise Circular Passenger-Side Antenna

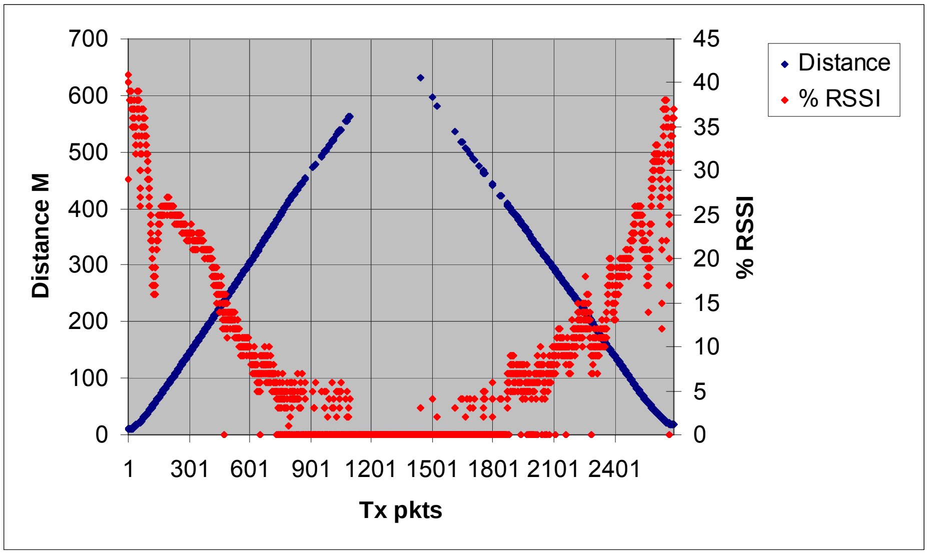


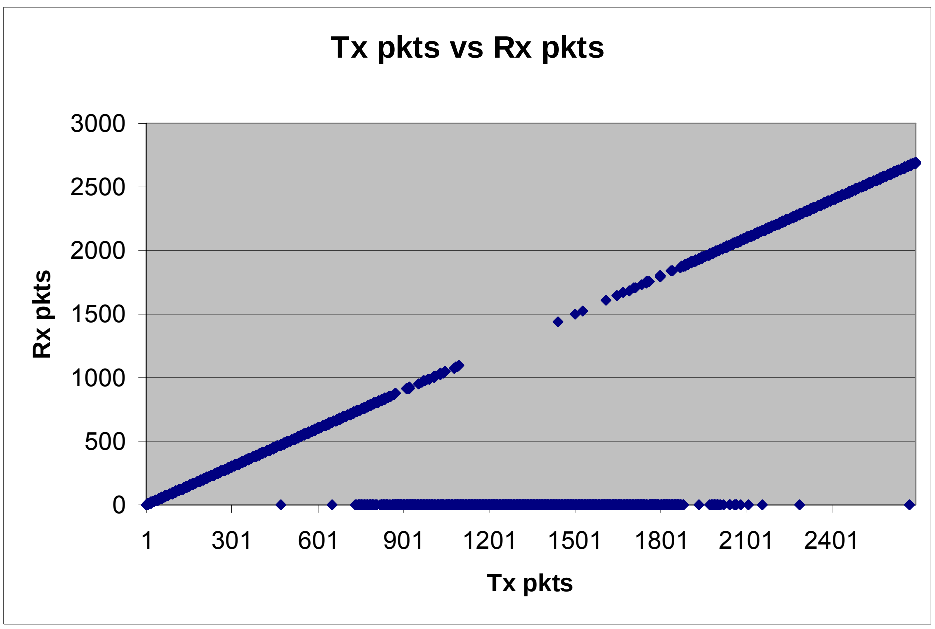


Total packets sent: 999

Total packets dropped: 0

3.6.6.4 GM 5 5890 Receiving Vehicle Front

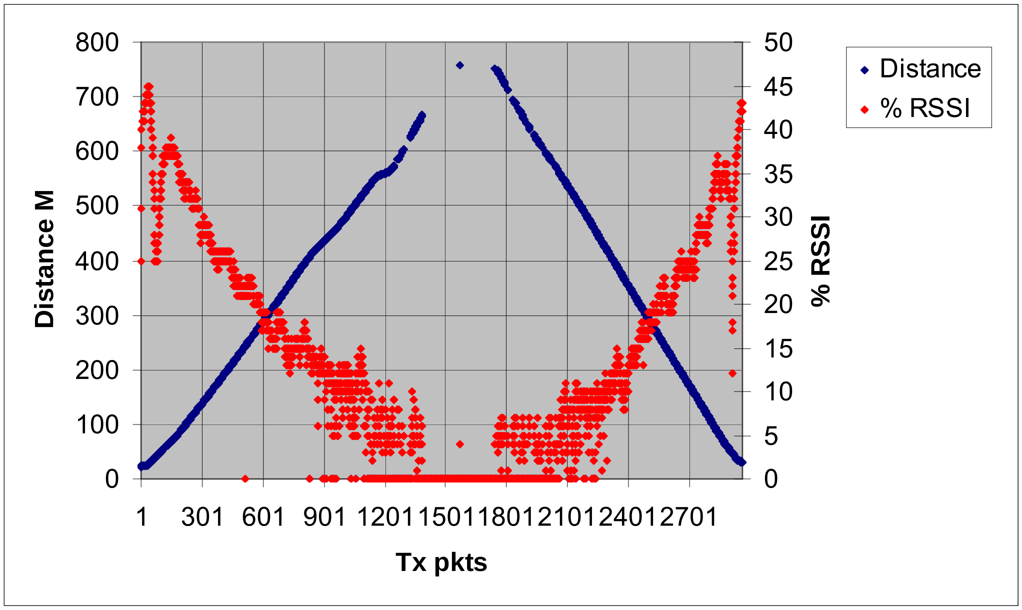


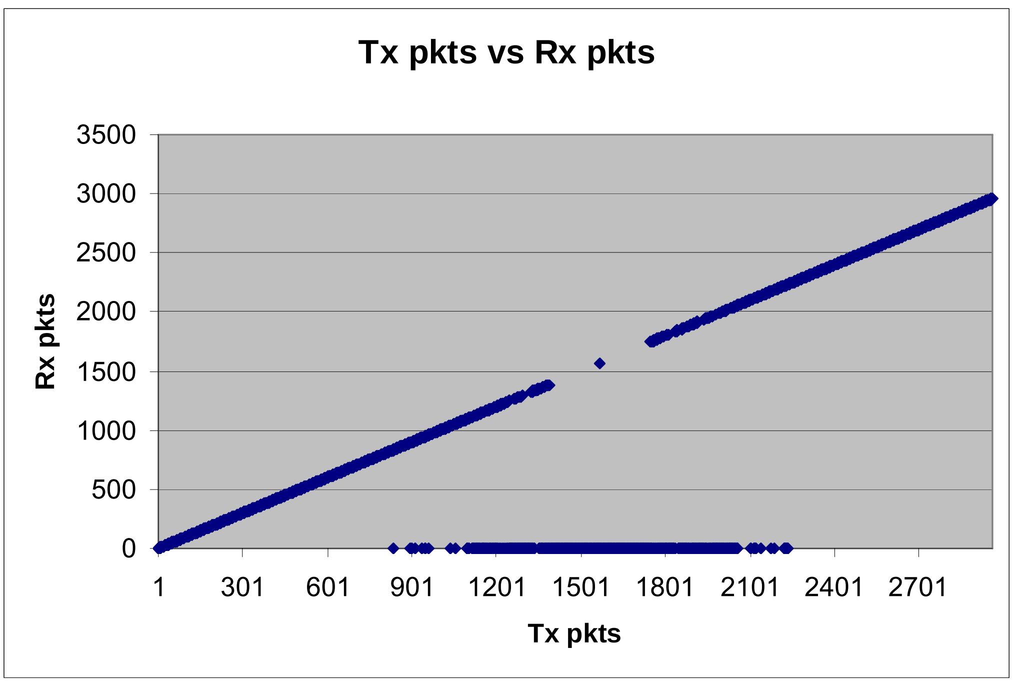


Total packets sent: 2691

Total packets dropped: 1036

3.6.6.5 GM 6 5200 Receiving Vehicle Front

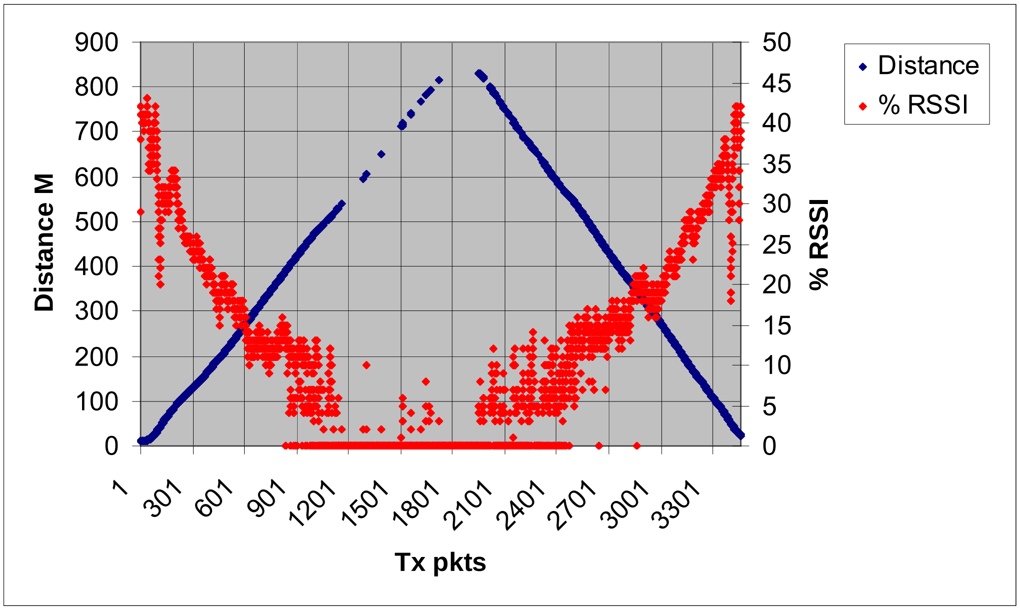


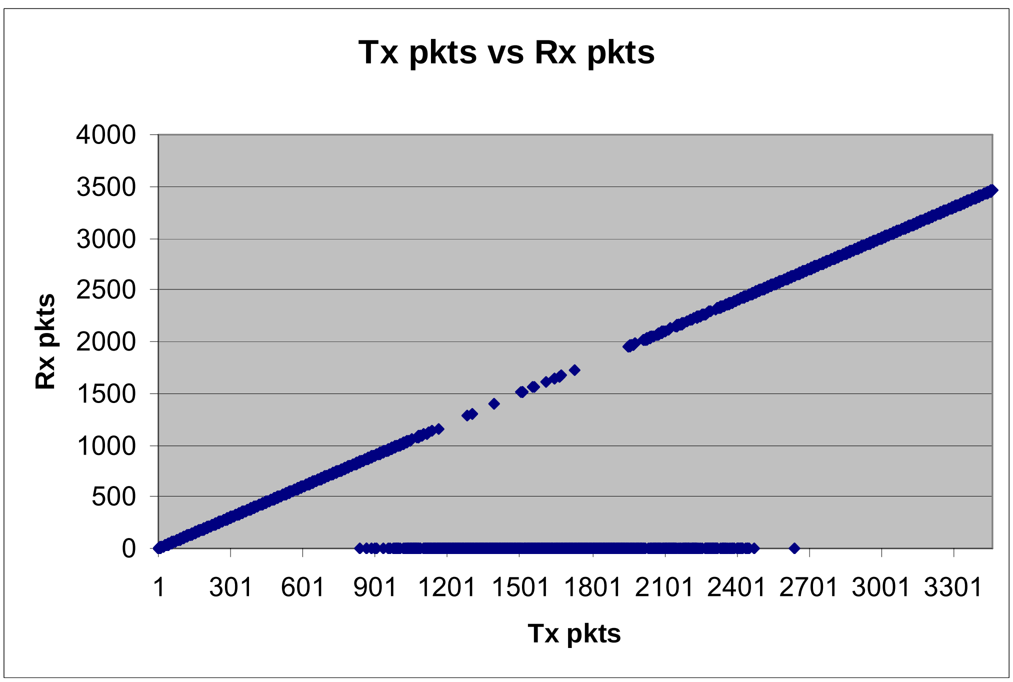


Total packets sent: 2960

Total packets dropped: 745

3.6.6.6 GM 7 5200 Receiving Vehicle Broadside

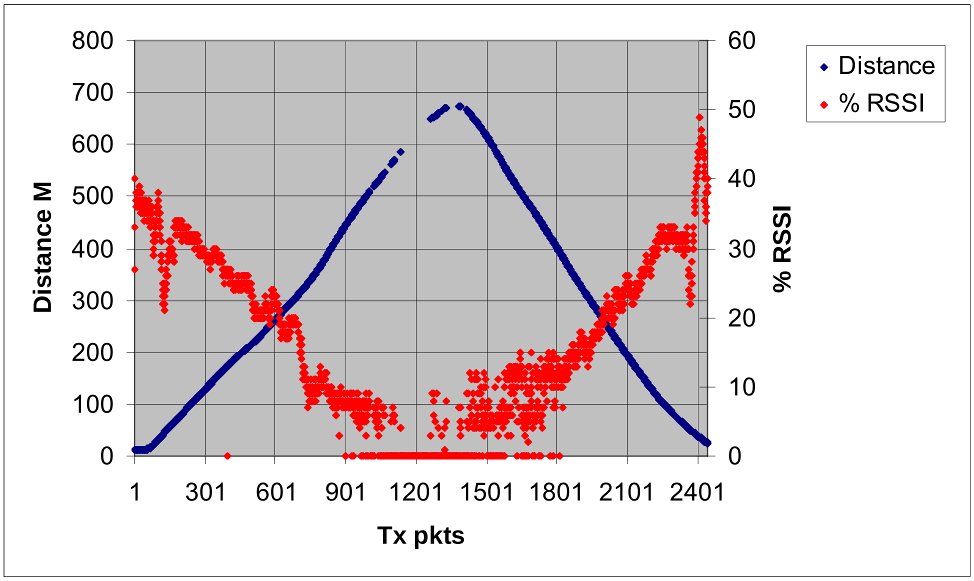


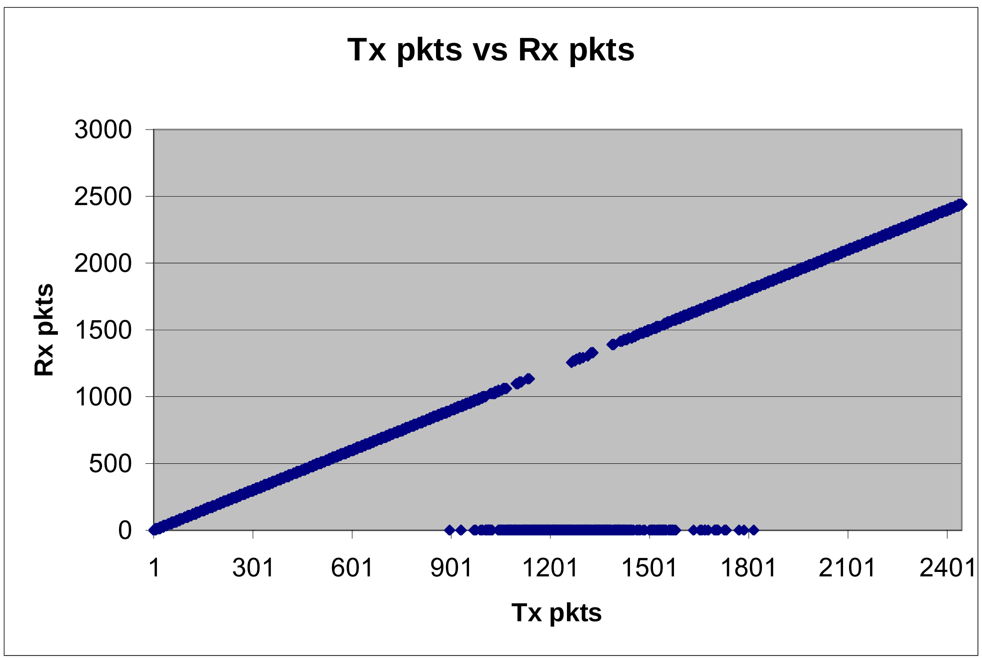


Total packets sent: 3460

Total packets dropped: 1161

3.6.6.7 GM 8 5320 Receiving Vehicle Rear

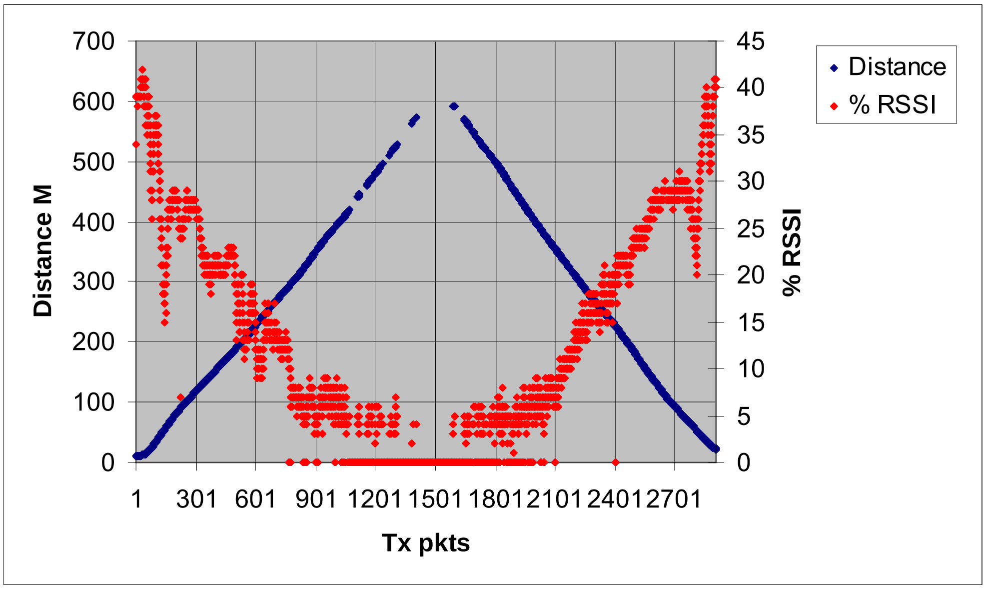


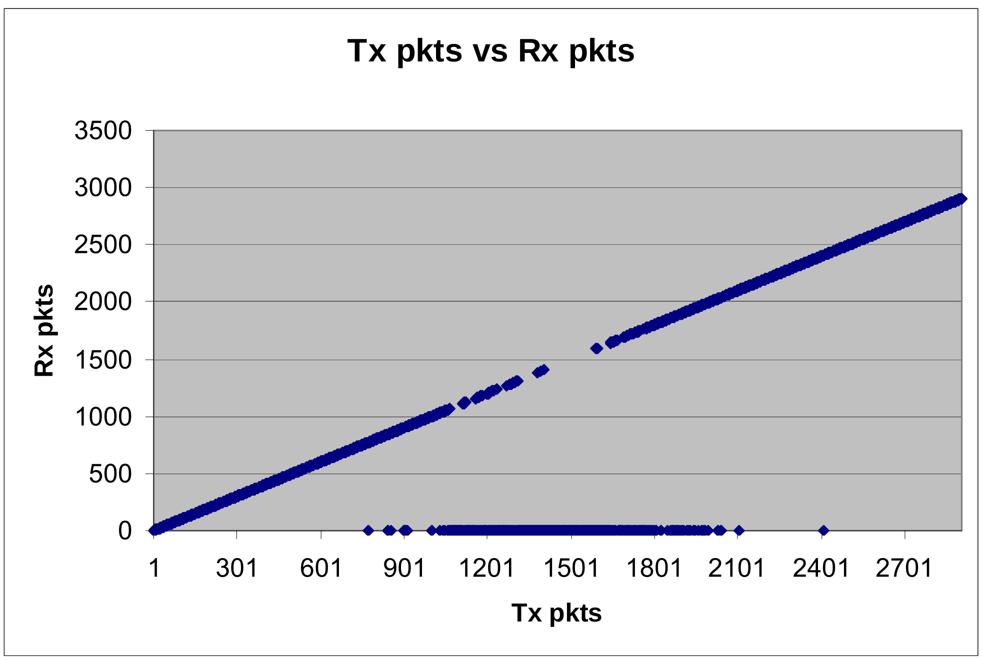


Total packets sent: 2442

Total packets dropped: 455

3.6.6.8 GM 11 5890 Receiving Vehicle Broadside

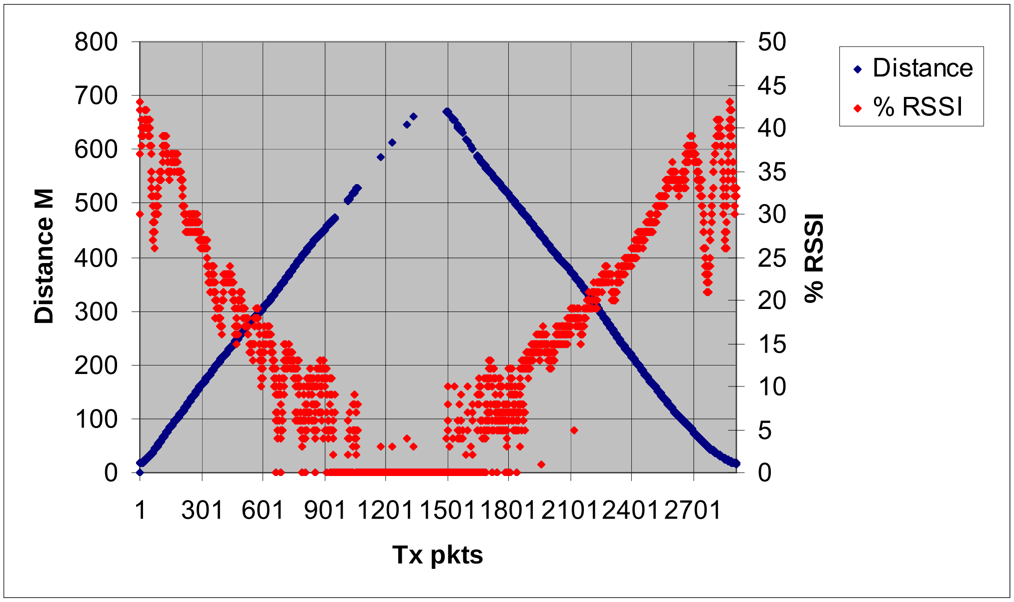


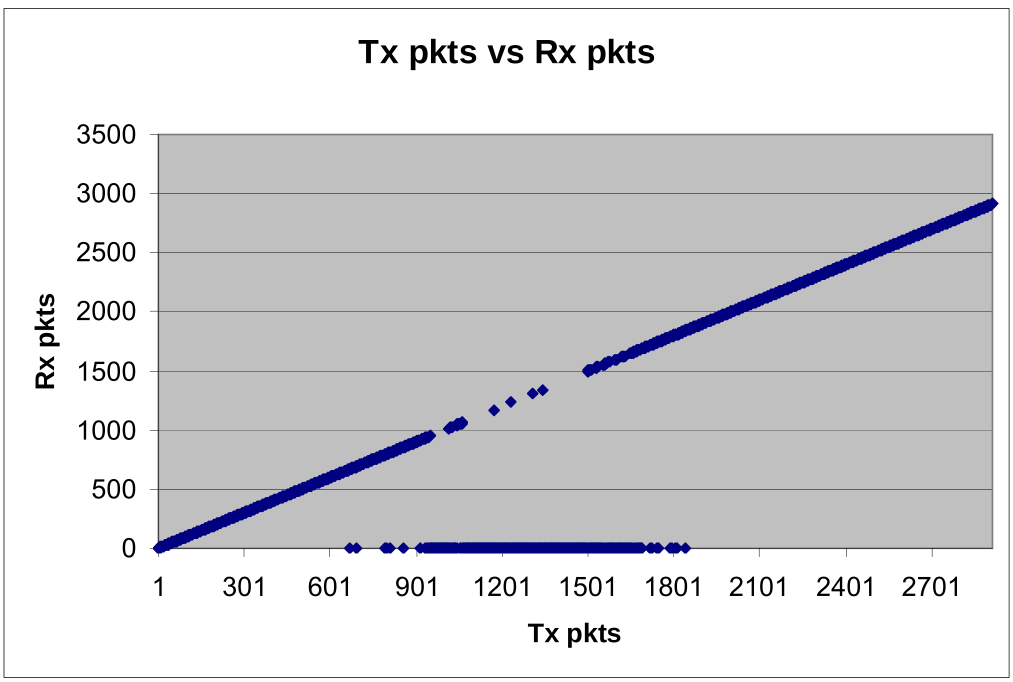


Total packets sent: 2905

Total packets dropped: 677

3.6.6.9 GM 9 5200 Receiving Vehicle Rear

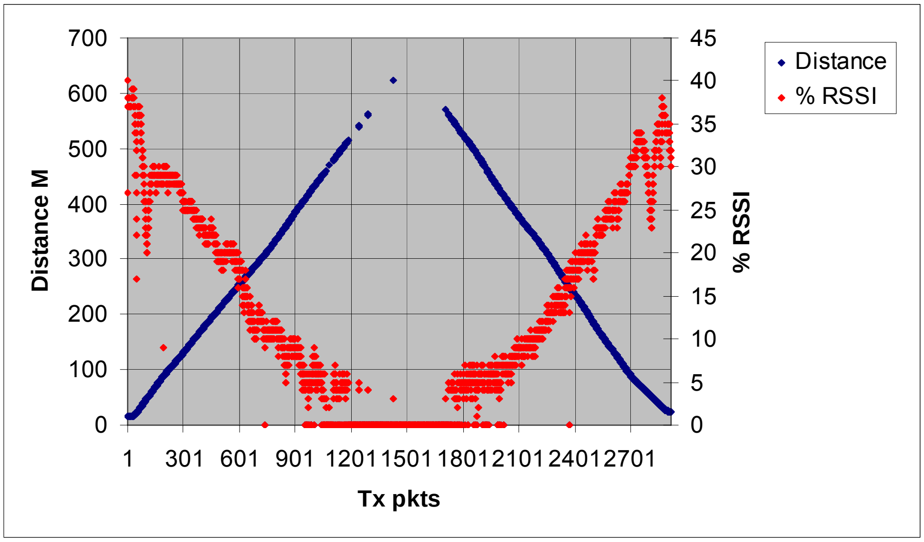


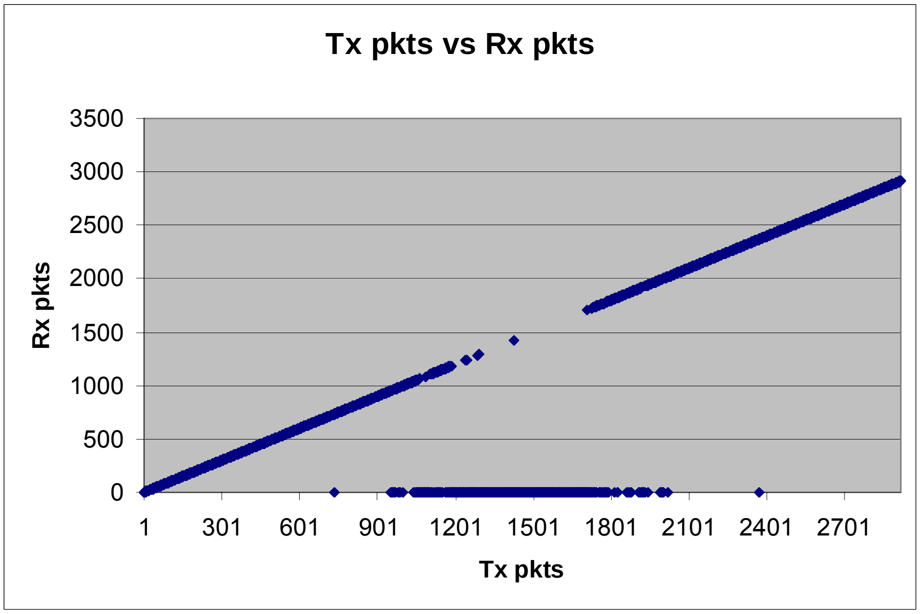


Total packets sent: 2912

Total packets dropped: 674

3.6.6.10 GM 10 5890 Receiving Vehicle Rear



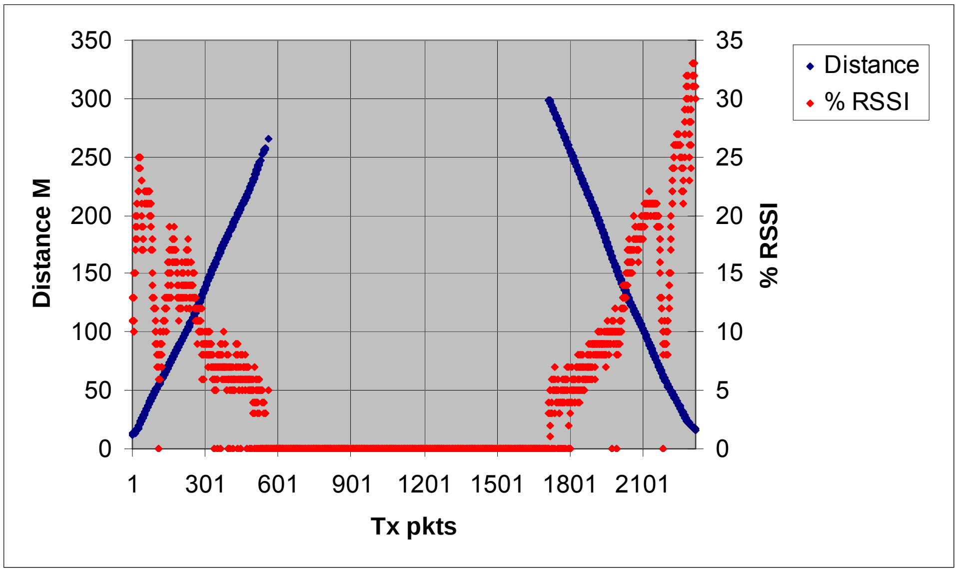


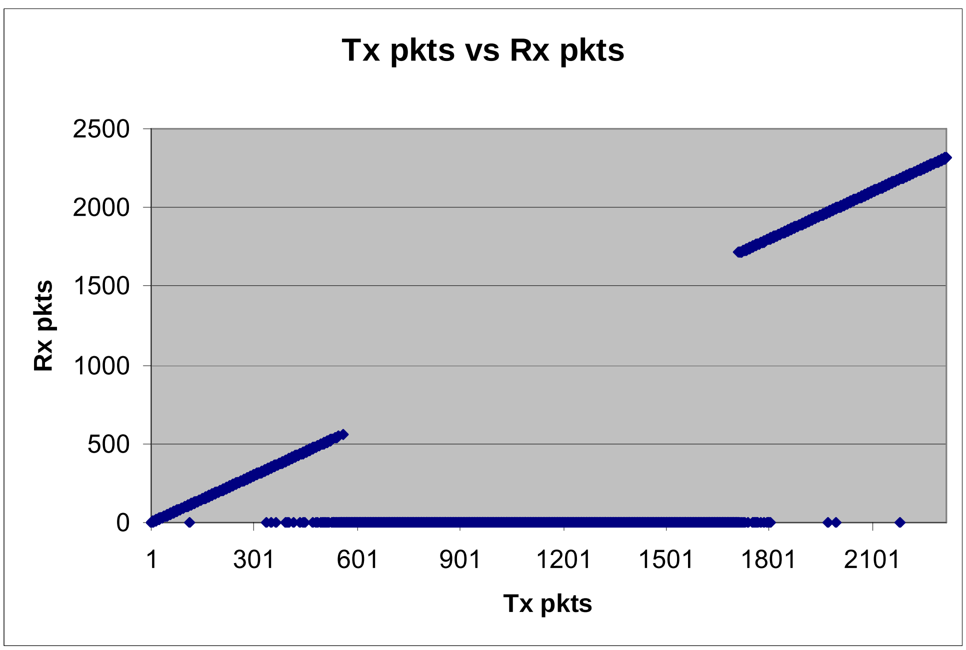
Total packets sent: 2915

Total packets dropped: 680

3.6.6.11 GM 12 5890 Receiving Vehicle Passenger-Side Broadside

Poor test kit auxiliary test port sensitivity first discovered.



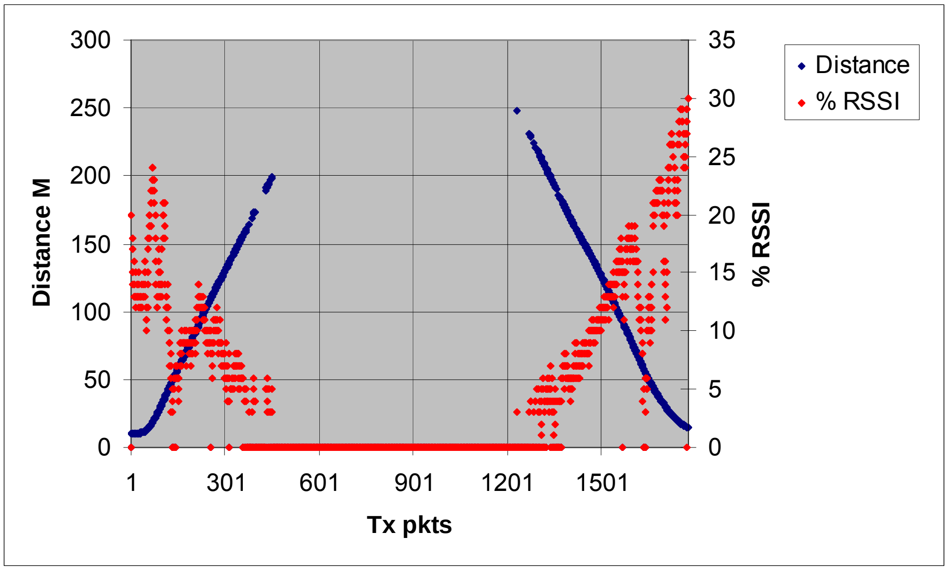


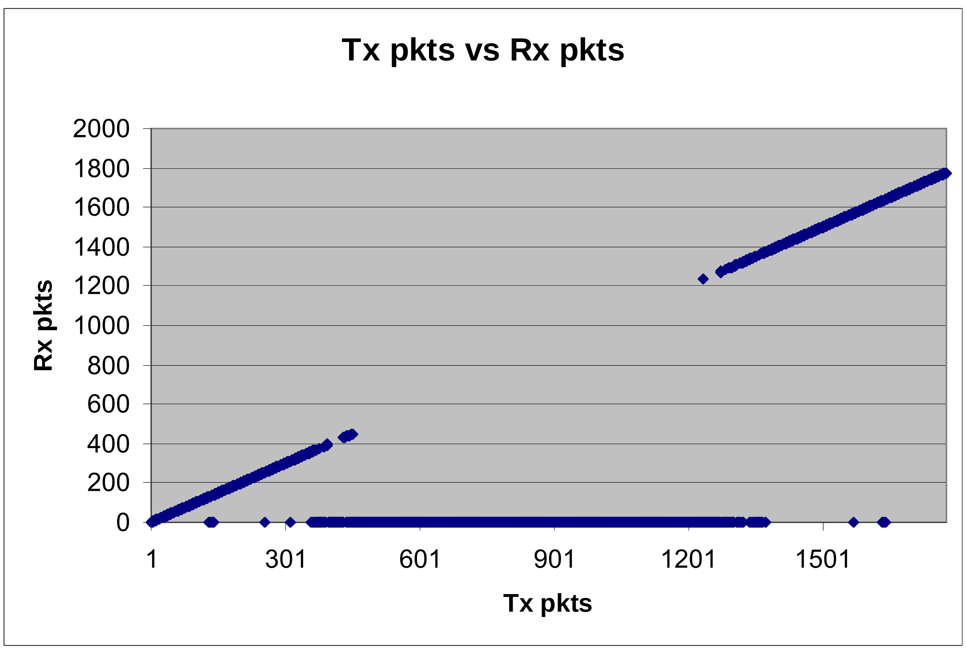
Total packets sent: 2316

Total packets dropped: 1223

3.6.6.12 GM 13 5890 Receiving Vehicle Passenger-Side Broadside

Passenger side antenna replaced with driver side antenna.



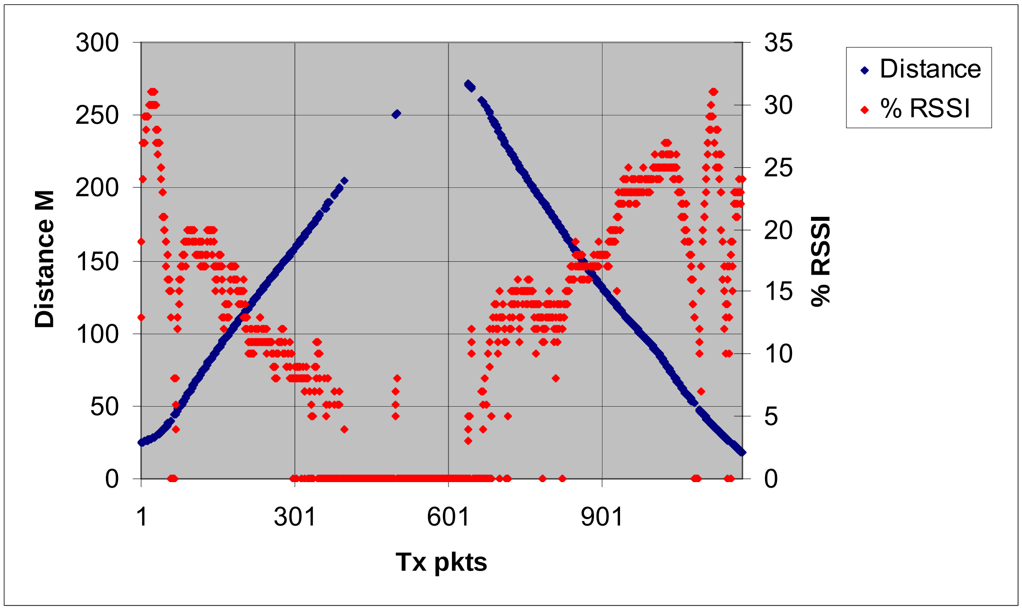


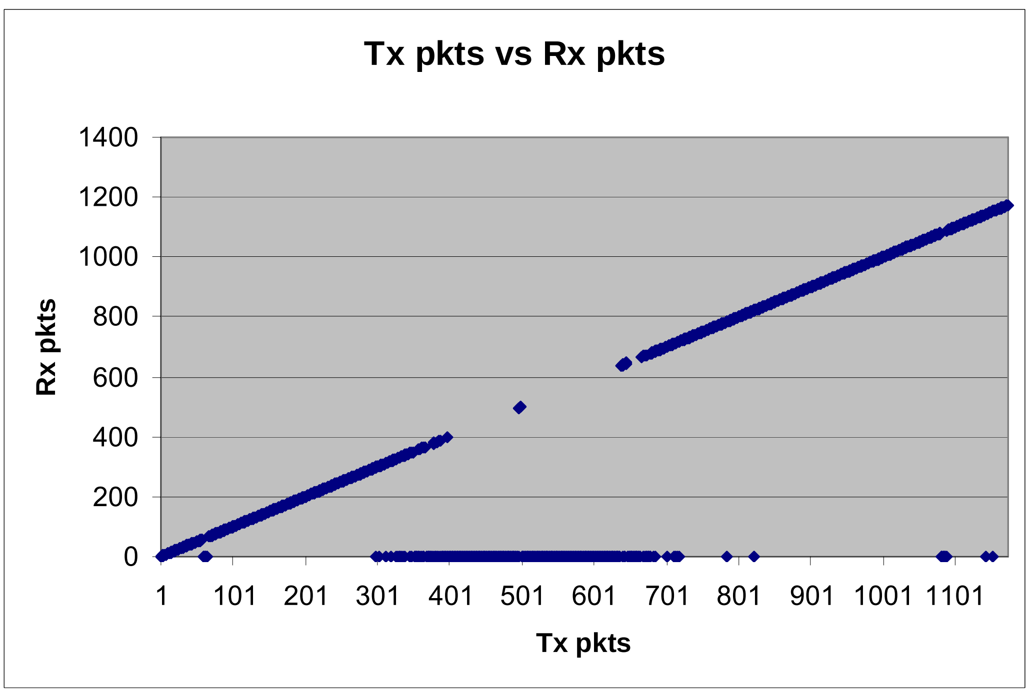
Total packets sent: 1776

Total packets dropped: 952

3.6.6.13 GM 14 5200 Receiving Vehicle Passenger-Side Broadside

Repeated GM 13 to investigate the possibility of frequency sensitivity.



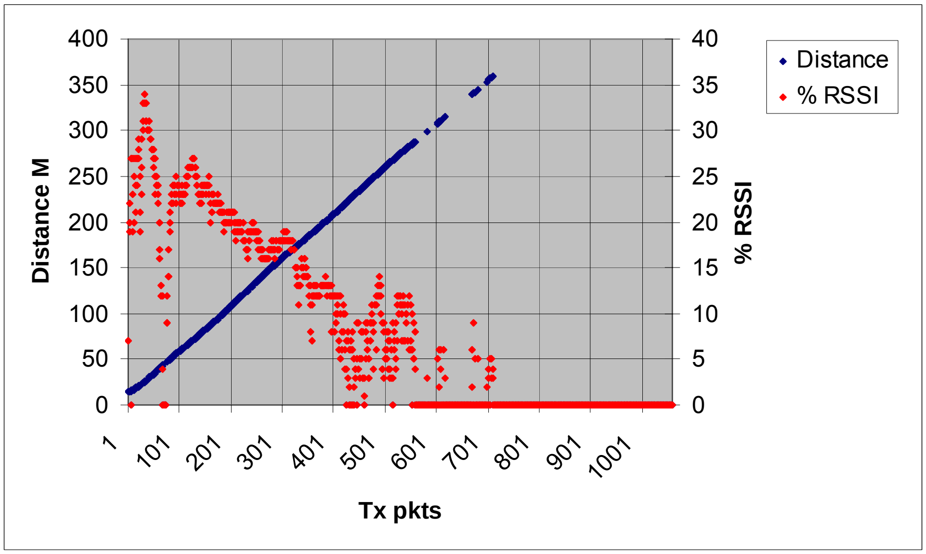


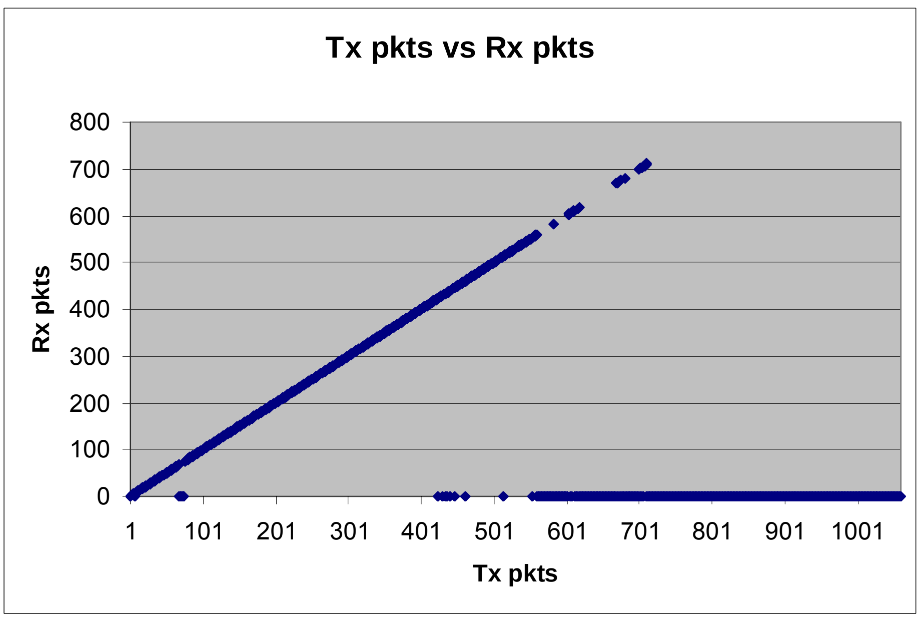
Total packets sent: 1173

Total packets dropped: 338

3.6.6.14 GM 15 5200 Receiving Vehicle Passenger-Side Broadside

All cables moved to swapped including test kit MMCX to SMA adapter using auxiliary input port.



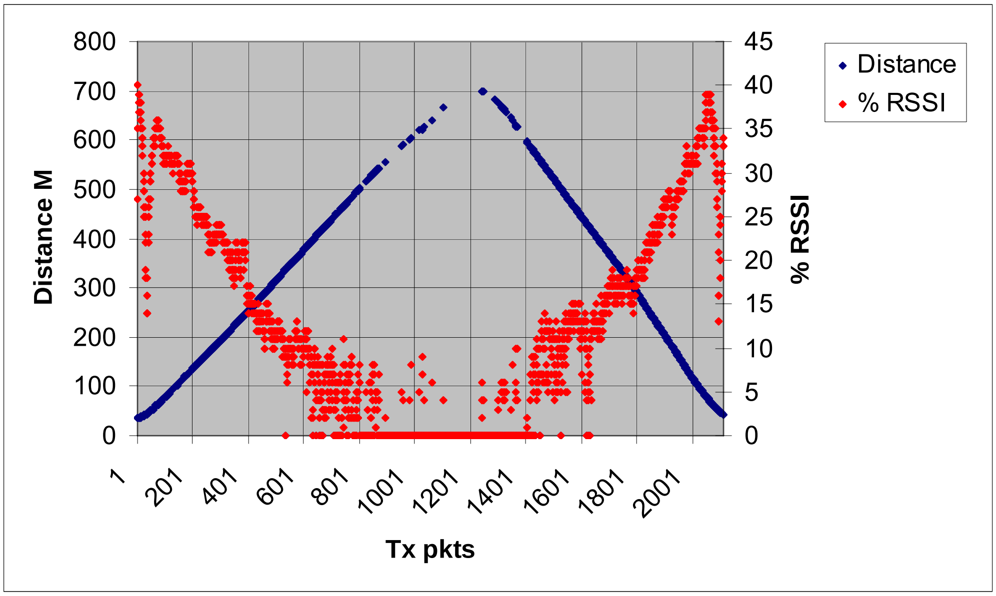


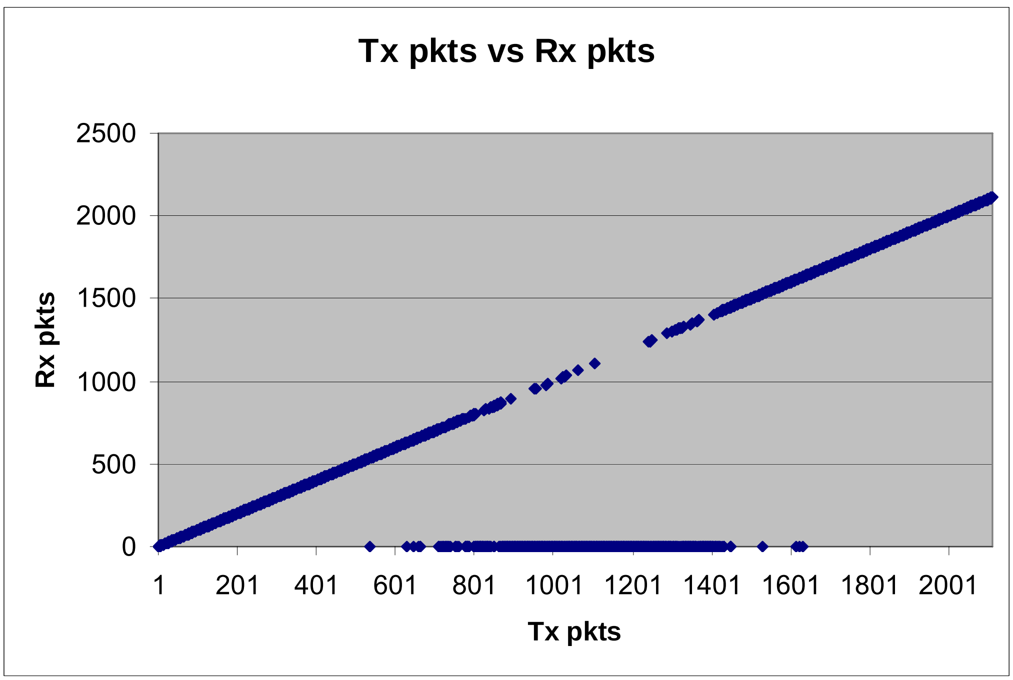
Total packets sent: 1059

Total packets dropped: 495

3.6.6.15 GM 16 5200 Receiving Vehicle Passenger-Side Broadside

Test kit cable MMCX end moved to main input port.

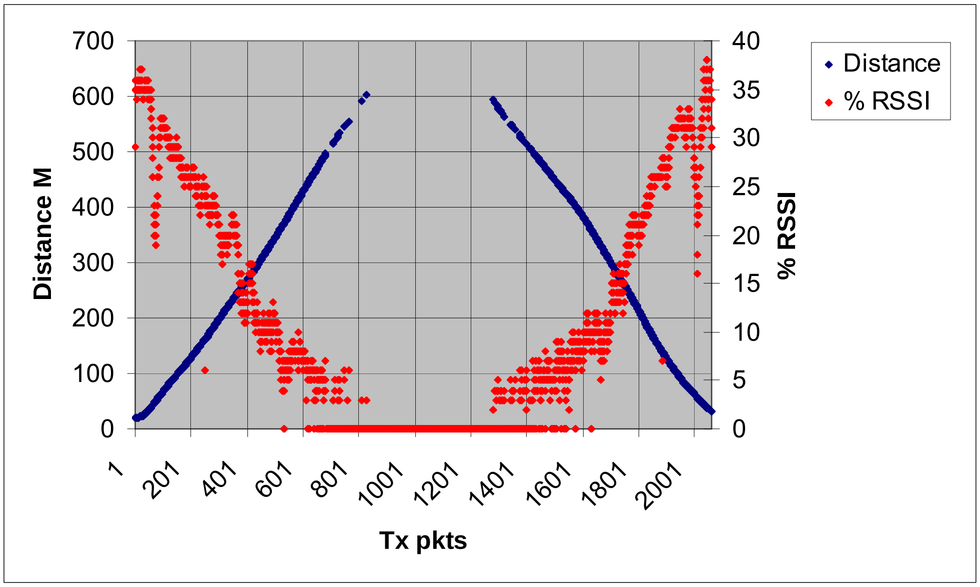


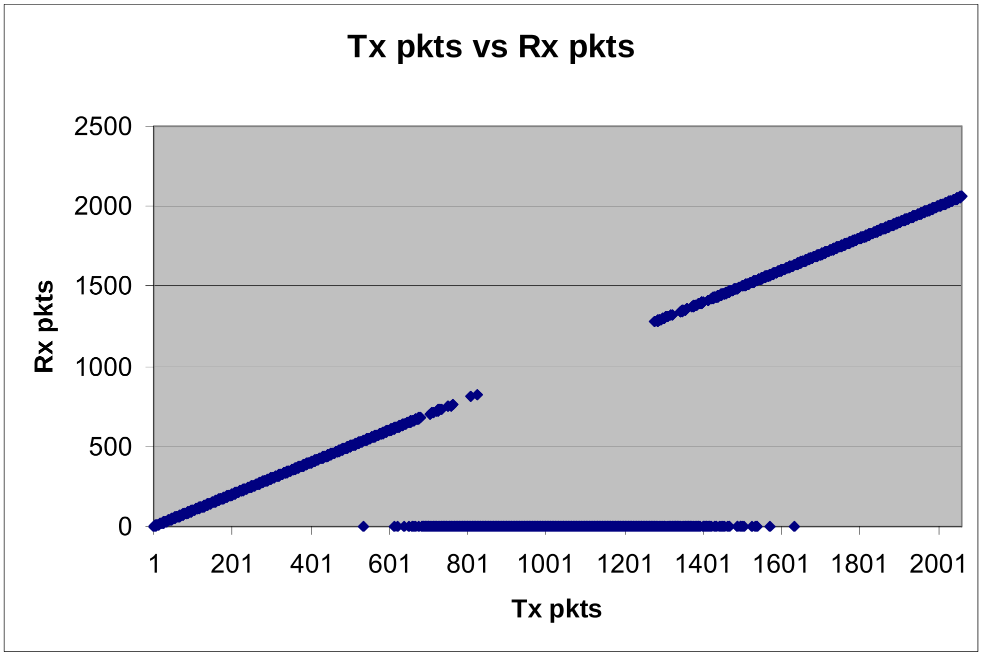


Total packets sent: 2111

Total packets dropped: 603

3.6.6.16 GM 17 5890 Receiving Vehicle Passenger-Side Broadside





Total packets sent: 2060

Total packets dropped: 720

3.6.6.17 *Summary – GM Proving Ground*

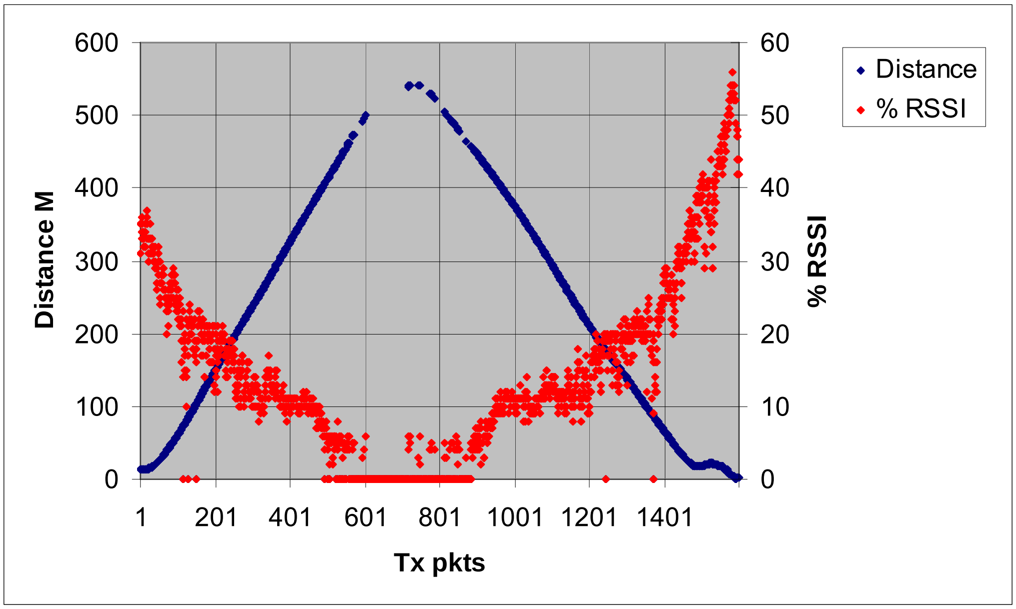
The mirror mount antenna configuration for these drive tests included only a single broadcasting antenna. Tests conducted at 5.2GHz indicate greater range than those taken at 5.89GHz. This is mainly due to the reduced transmit power of the test kits at the higher frequency as both frequencies are within the bandwidth of the antenna. Therefore, the expected performance will be similar to or better than tests conducted at 5.2GHz.

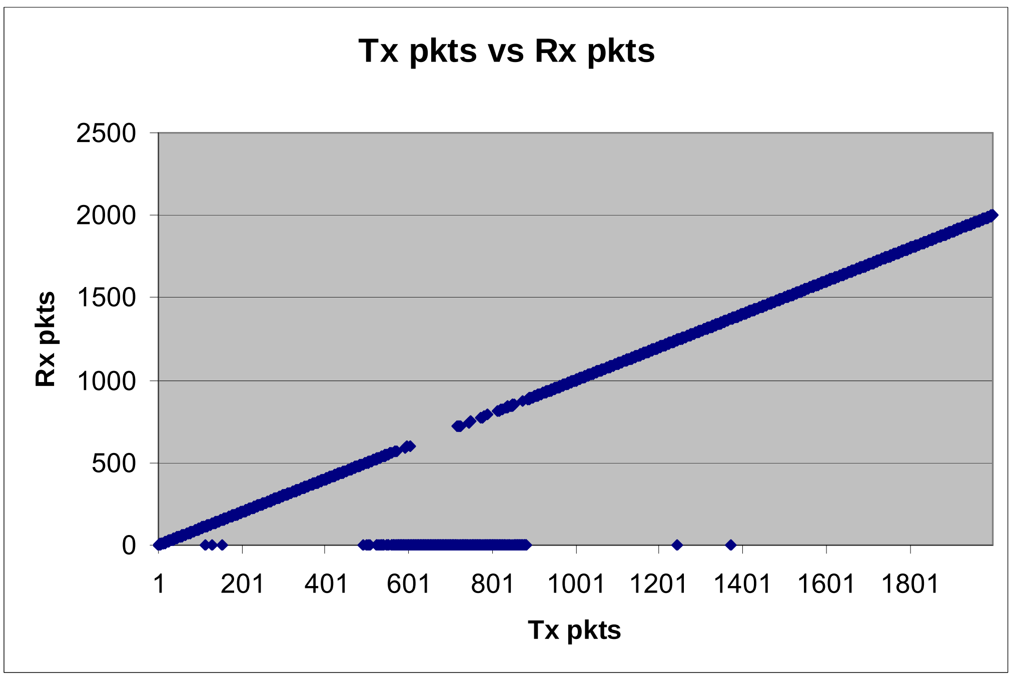
3.6.7 Test Results – Troy 5/8 Wave Roof Mount Antenna

Because the 5/8 wave roof mount antenna was not yet available for drive testing at the GM Proving Ground, these drive tests were subsequently conducted along a dead-end side street. This same street was used for preliminary testing with prototype mirror mount antennas and provides a clear unobstructed range of 550 meters. It should be noted that these particular drive tests occurred in the presence of rain.

Drive tests were conducted using a receiving vehicle with a sunroof and a transmit vehicle without a sunroof. The main antenna port of each test kit was connected to the 5/8 wave antenna pig tail with a 6-foot-long coaxial extension cable. The coaxial extension cable is made of LMR-195 coaxial cable and has a measured 2dB insertion loss at 5.888GHz. The 5/8 wave antenna was located on the receiving vehicle roof 7.5 inches rearward of the sunroof rear edge along the vehicle front-to-back center line. The transmit vehicle 5/8 wave antenna was located at the roof center.

3.6.7.1 SS2 5890 Receiving Vehicle Front

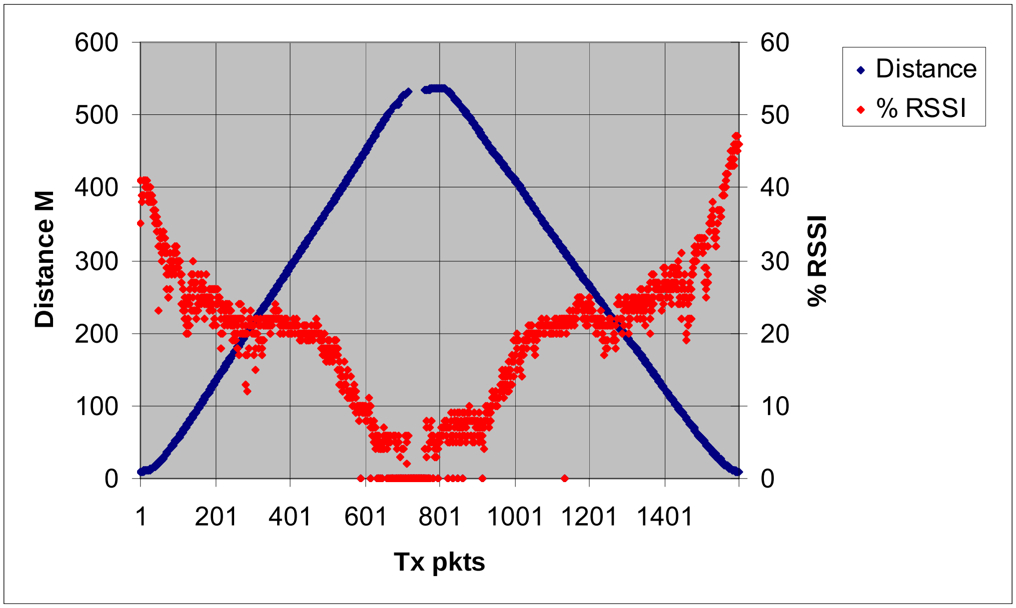


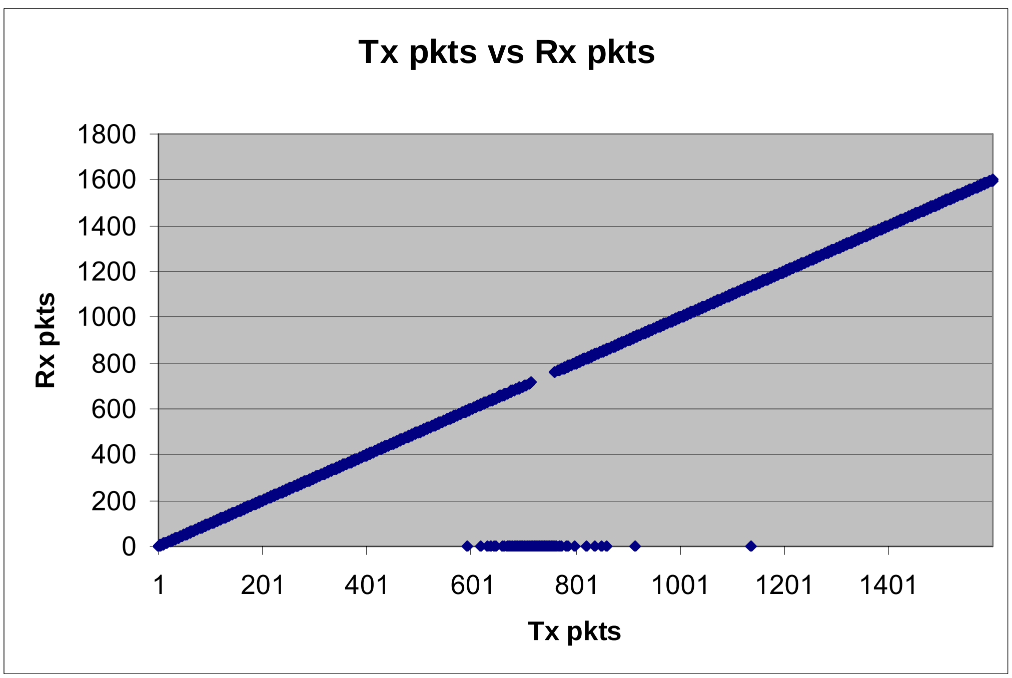


Total packets sent: 1999

Total packets dropped: 314

3.6.7.2 SS3 5890 Receiving Vehicle Rear





Total packets sent: 1599

Total packets dropped: 96

3.6.7.3 Propagation Model

Because the 5/8 wave antenna is not resonant in the WLAN band where the test kits have increased transmit power, the expected range cannot be directly measured. However the expected range can be modeled using the 5.8875GHz radiation pattern, Figure 54, 2dB extension cable loss, and height information of the vehicle with sunroof. The measured gain in Figure 54 at 0° is –4dBil corresponding to the receiving vehicle front configuration, and at 180° is 0dBil corresponding to the receiving vehicle rear configuration.

For the receiving vehicle front case, the propagation model results were computed at SS2 range points to facilitate an overlay comparison shown in Figure 61. Because the receiving and transmitting antenna gain and cable loss are known quantities, to correlate with the model, the transmit power at the time of these drive tests was approximately 50mW.

	tx	rx	
	Vehicle 1	Vehicle 2	
Ant gain	-4	1	dBil
El HPBW	10	10	°
tilt	0	0	° ± up/dn
height	1.4	1.4	M
Cable loss	2.00	2.00	dB
TX power	50.00		mW

Range	5	600	M
Frequency	5.89	GHz	
MDS	-86	dB	

Ground permittivity		
ε'	1	
ε"	-1.50E+01	
Brewster	45	deg
Range	2.8	M

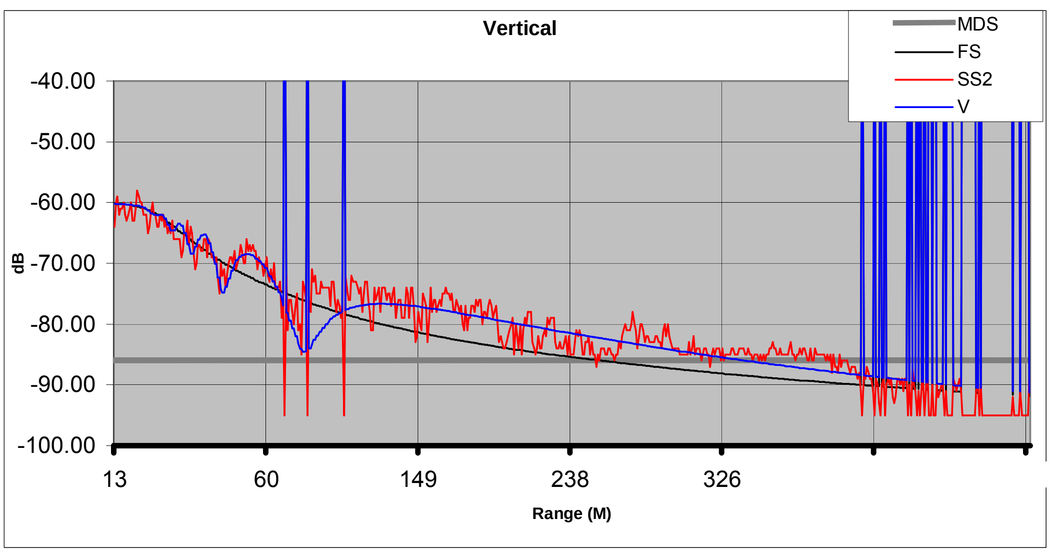


Figure 3-AA. Comparison of Propagation Model and SS2 Data

Similarly for the receiving vehicle rear configuration using 0dBil antenna gain, the model and measured, SS3 data, comparison is shown in Figure 62.

	tx	rx	
	Vehicle 1	Vehicle 2	
Ant gain	0	1	dBil
El HPBW	10	10	°
tilt	0	0	° ± up/dn
height	1.4	1.4	M
Cable loss	2.00	2.00	dB
TX power	50.00		mW

Range	5	600	M
Frequency	5.89	GHz	
MDS	-86	dB	

Ground permittivity		
ε'	1	
ε"	-1.50E+01	
Brewster	45	deg
Range	2.8	M

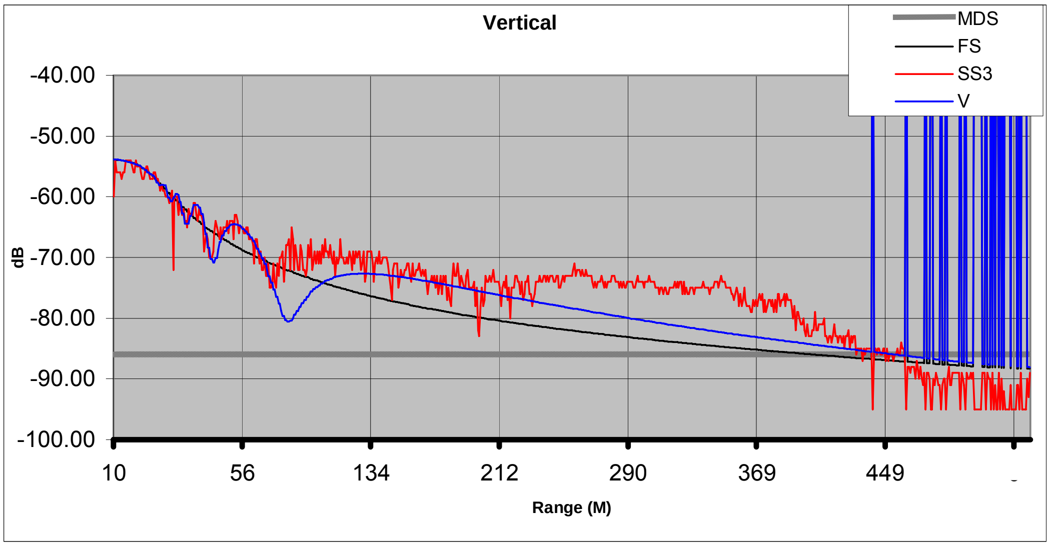


Figure 3-BB. Comparison of Propagation Model and SS3 Data

The modeled and measured data show good correlation with the 50mW transmit power approximation. Using this model and increasing the transmit power to 100mW for each case yields an approximate range of 424 meters for SS2 and 569 meters for SS3 shown in Figures 63 and 64 respectively. The modeled range predictions are considered conservative as the model assumes no packets can be received for signal levels below –86dBm at the receiver.

	tx	rx	
	Vehicle 1	Vehicle 2	
Ant gain	-4	1	dBil
El HPBW	10	10	°
tilt	0	0	° ± up/dn
height	1.4	1.4	M
Cable loss	2.00	2.00	dB
TX power	100.00		mW

Range	10	700	M
Frequency	5.89	GHz	
MDS	-86	dB	

Ground permittivity		
ε'	1	
ε"	-1.50E+01	
Brewster	45	deg
Range	2.8	M

424.69 M

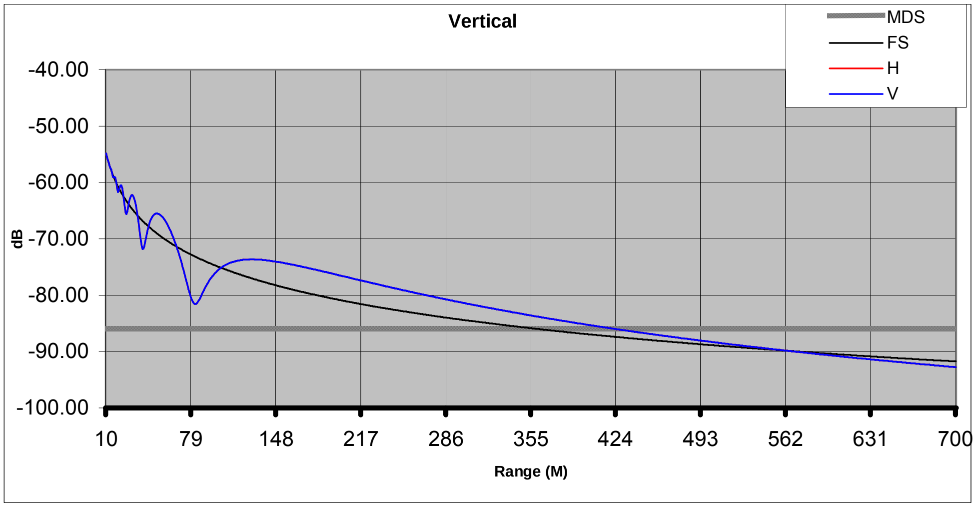


Figure 3-CC. Approximate Range for Receiving Vehicle Front With Sunroof

	tx	rx	
	Vehicle 1	Vehicle 2	
Ant gain	0	1	dBil
El HPBW	10	10	°
tilt	0	0	° ± up/dn
height	1.4	1.4	M
Cable loss	2.00	2.00	dB
TX power	100.00		mW

Range	10	700	M
Frequency	5.89	GHz	
MDS	-86	dB	

569.59 M

Ground permittivity		
ε'	1	
ε"	-1.50E+01	
Brewster	45	deg
Range	2.8	M

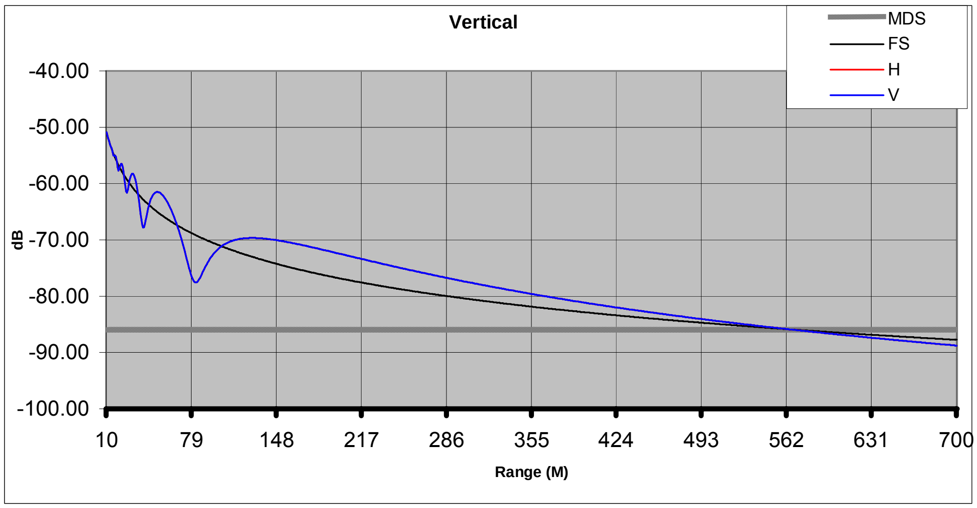


Figure 3-DD. Approximate Range for Receiving Vehicle Rear With Sunroof

3.6.7.4 Summary – Side Street Drive Tests

Both the vehicle radiation patterns measured at JEF and this drive testing show the effects of a sunroof on the effective communications range. While data packets were received at ranges beyond 500 meters with less than 100mW of transmit power, more packets were received in the rearward direction of the vehicle than in the forward direction as a consequence of the sunroof.

3.6.8 Summary – Drive Tests

Through extensive drive testing, the mirror mount antennas have shown to consistently provide good vehicle communications over both WLAN and ITS DSRC bands to at least 500 meters ±90° broadside of the vehicle.

The 5/8 roof mount antenna performance can be influenced by vehicle roof surface features such as a sunroof. However for recommended roof locations, the 5/8 wave antenna also meets design and performance goals.

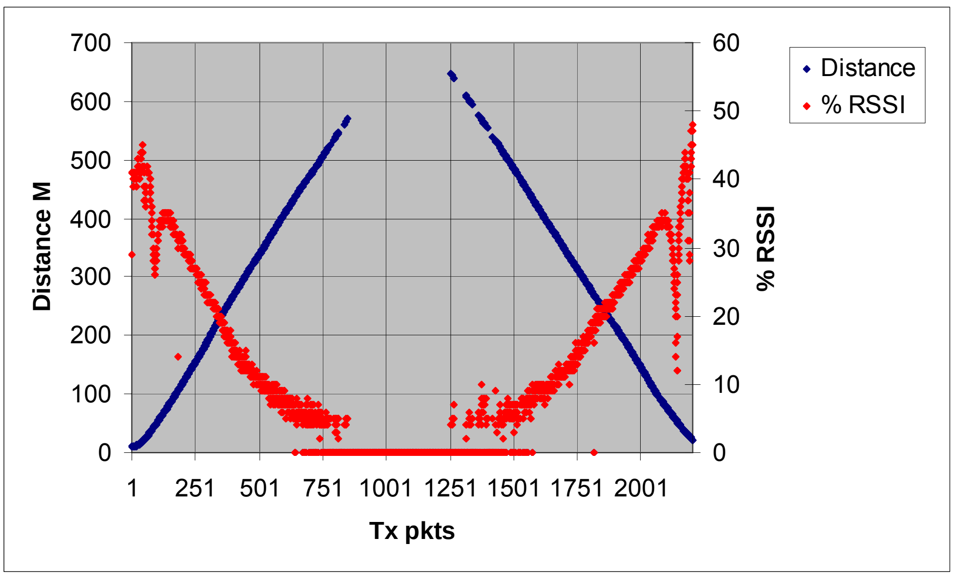
3.7 Summary

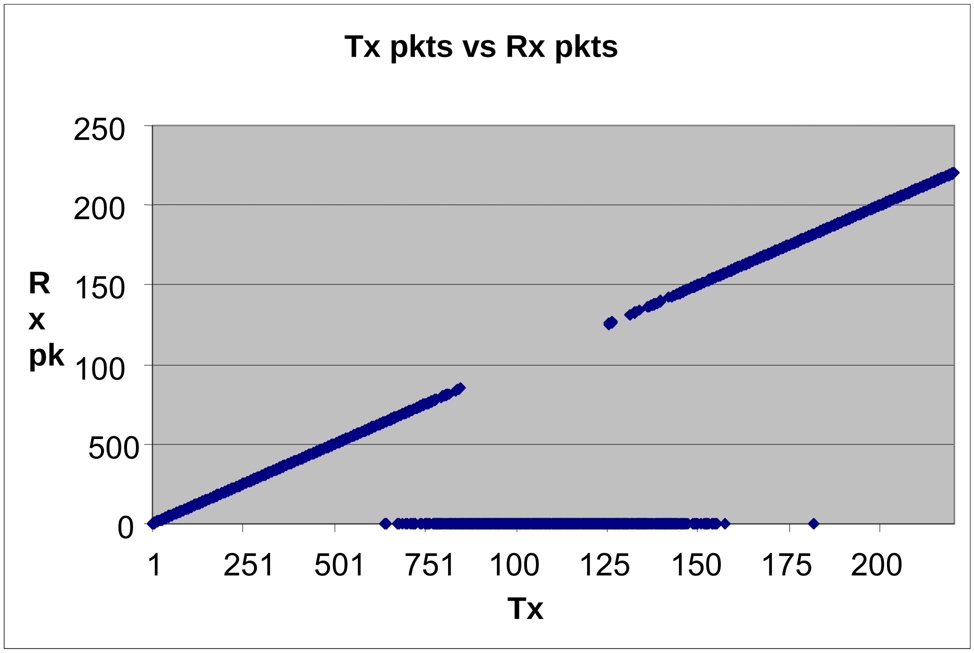
Two antennas have been designed, built, and tested both at component level and vehicle level. The results show that both antennas perform as designed and meet all goals of the design specification. Because the performance of each antenna can be influenced by vehicle type, the results reported here are typical for sedan type vehicles.

3.7.1 Test Results – Mirror Mount Ford Proving Ground

Drive testing of the mirror mount antenna was conducted at the Ford Proving Ground in Dearborn, MI. The initial tests resulted in poor range performance due to a problem with the coaxial extension cables which connect the test kit to the antenna pigtail. Subsequently, the test kits were connected directly to the antenna pigtail in each vehicle.

3.7.1.1 Ford 12 5890 Receiving Vehicle Front

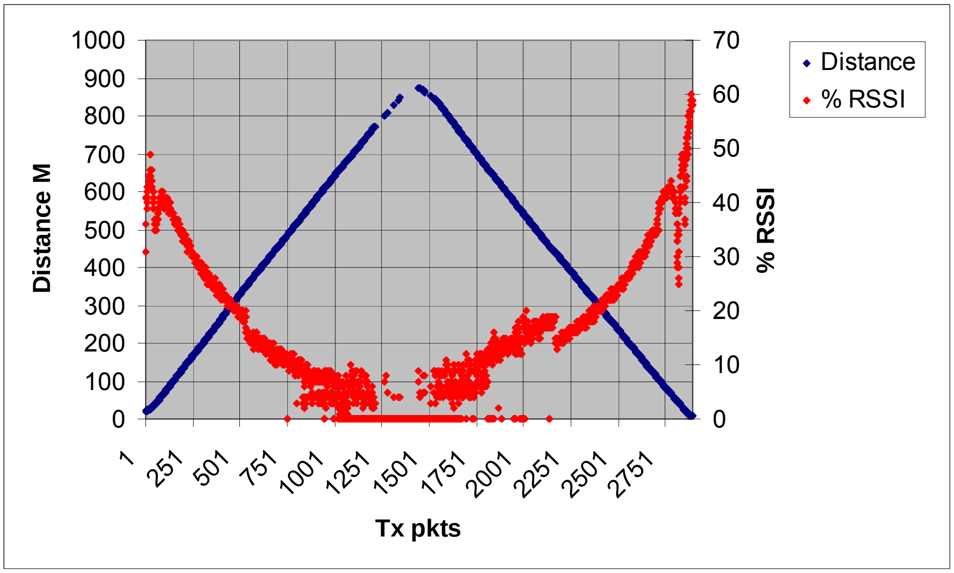


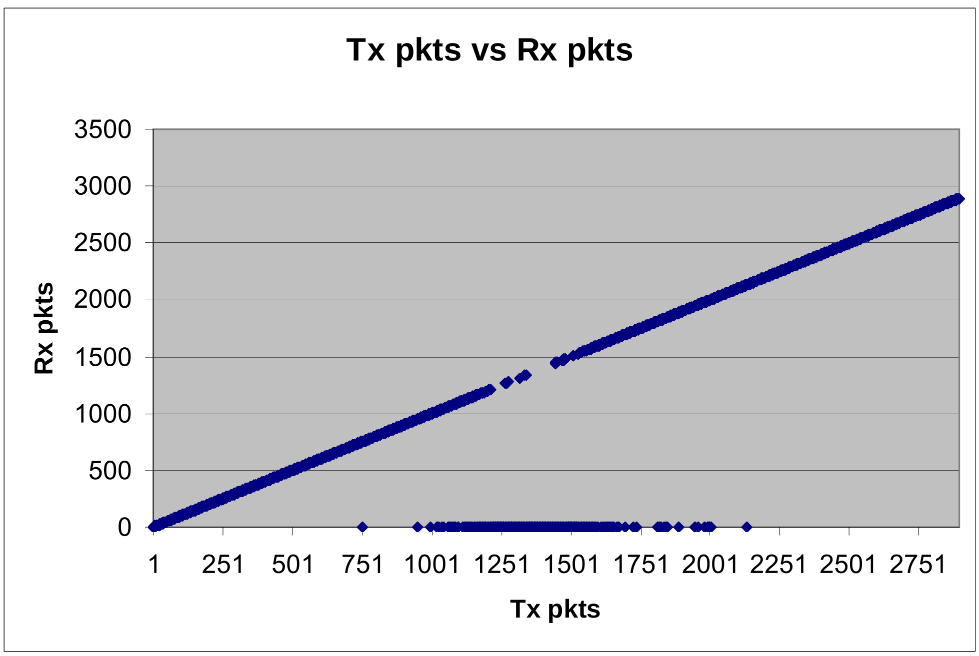


Total packets sent: 2203

Total packets dropped: 676

3.7.1.2 Ford 13 5300 Receiving Vehicle Front



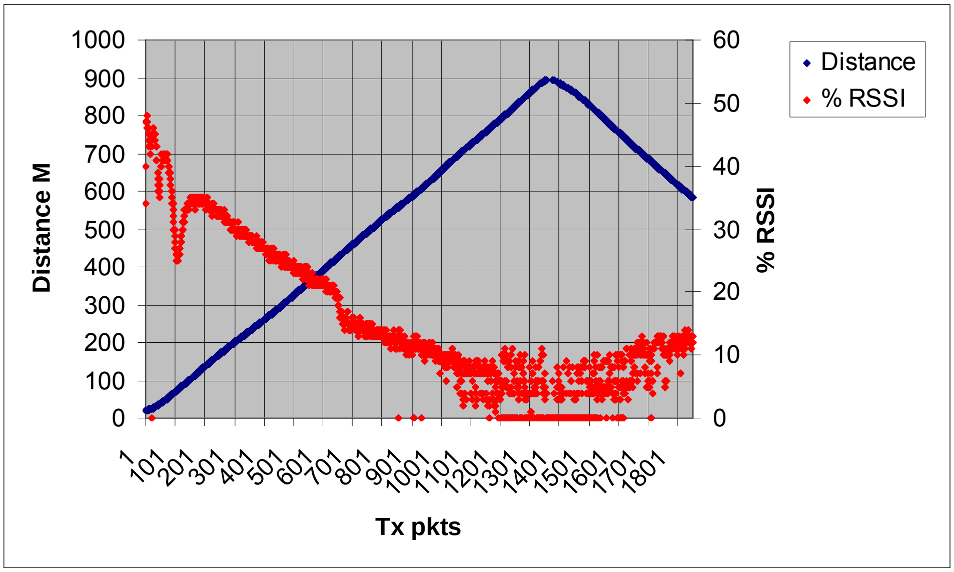


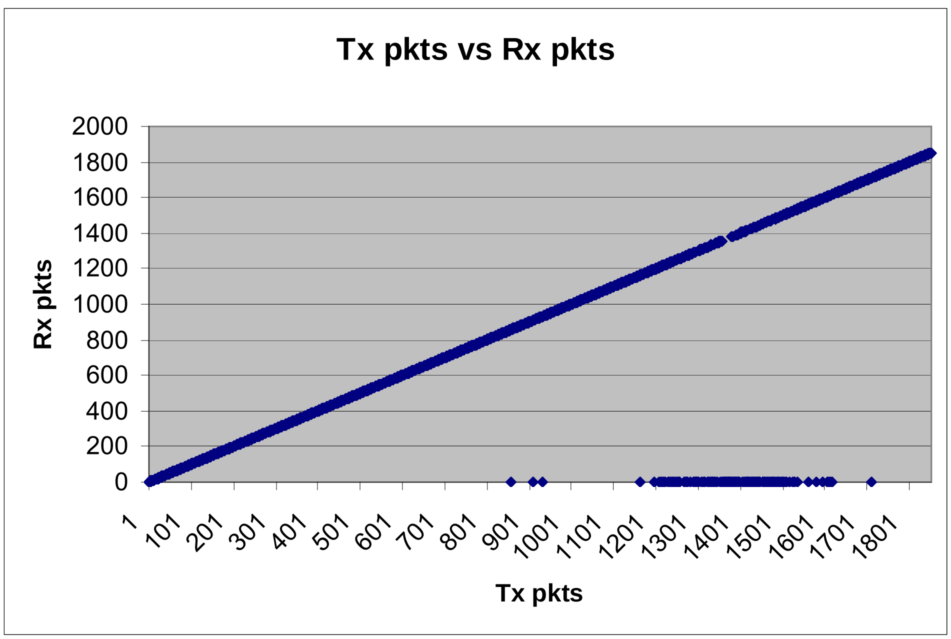
Total packets sent: 2894

Total packets dropped: 444

3.7.1.3 Ford 9 5300 Receiving Vehicle Broadside

This test is using the 4-element array antenna on loan from CAMP on both vehicles to ensure proper test kit operation.

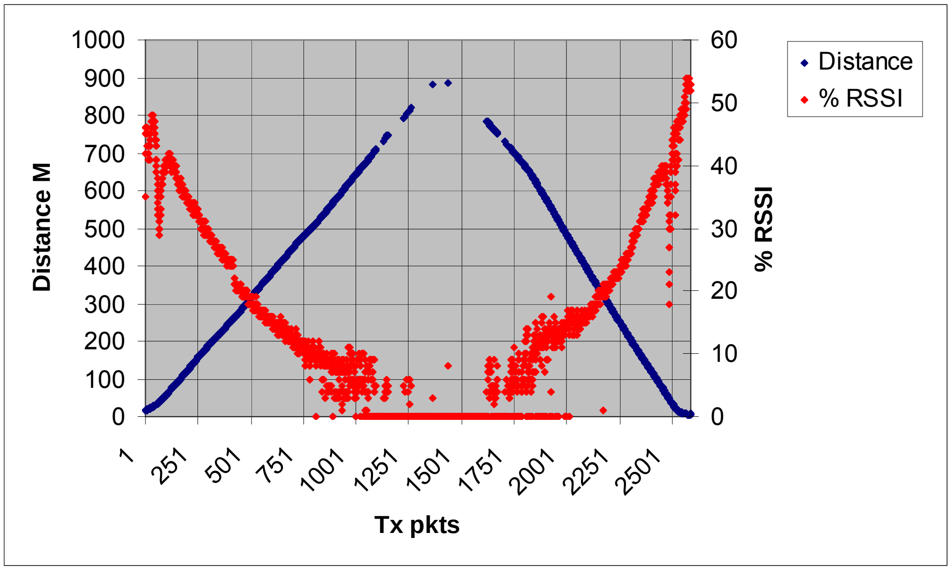


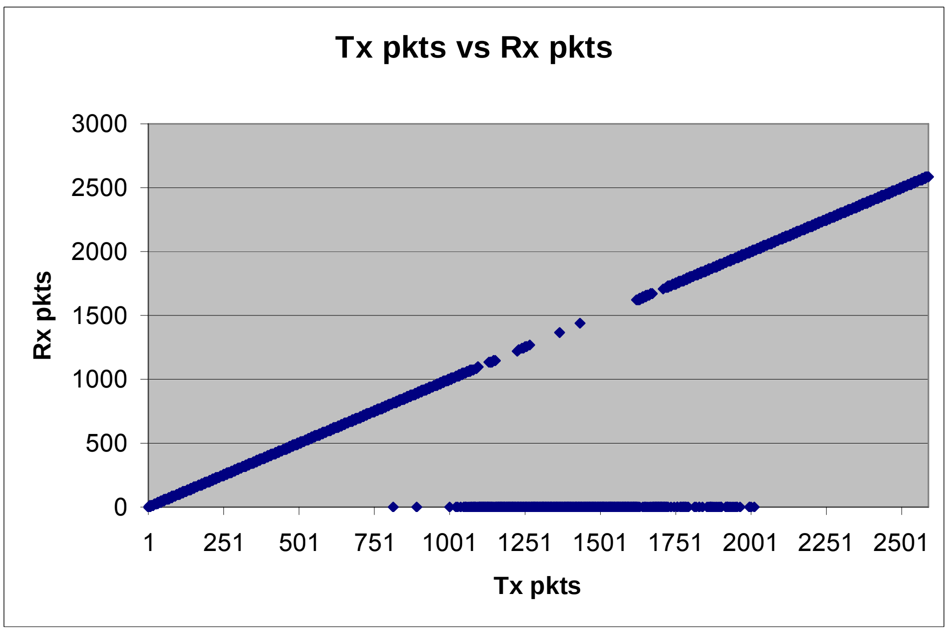


Total packets sent: 1852

Total packets dropped: 164

3.7.1.4 *Ford 10 5300 Receiving Vehicle Broadside*

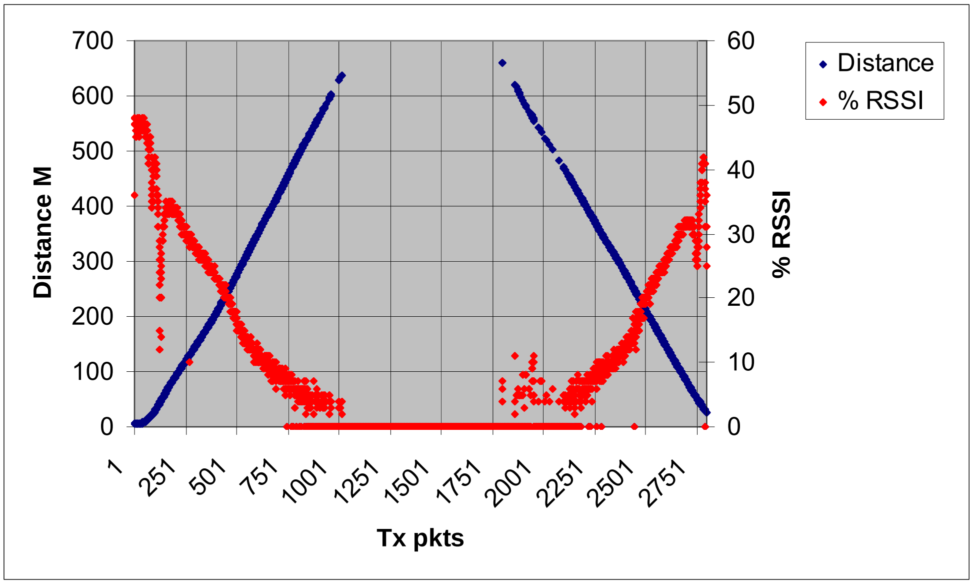


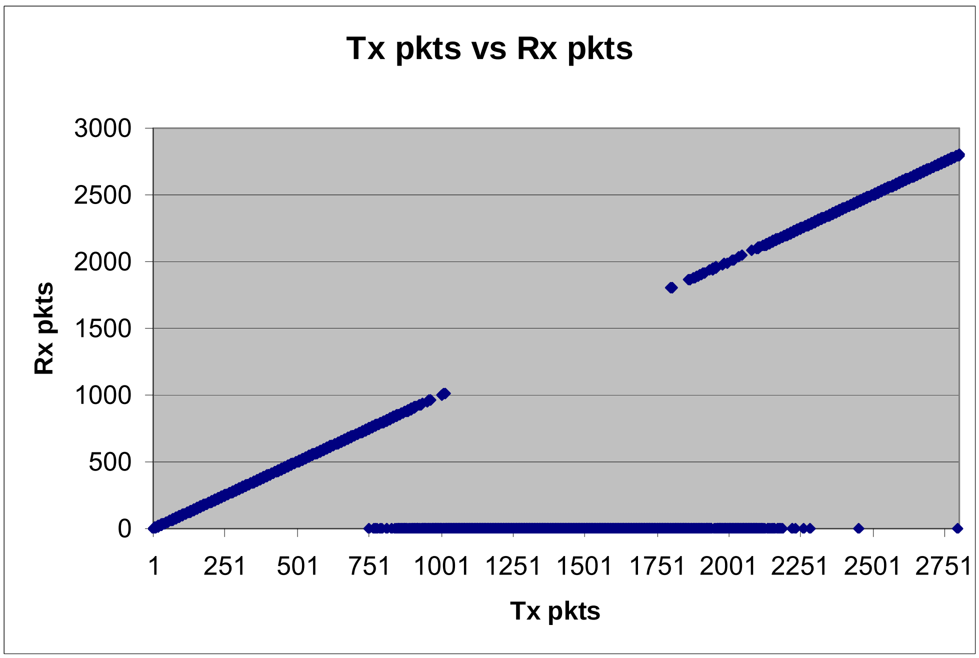


Total packets sent: 2588

Total packets dropped: 645

3.7.1.5 Ford 11 5890 Receiving Vehicle Broadside

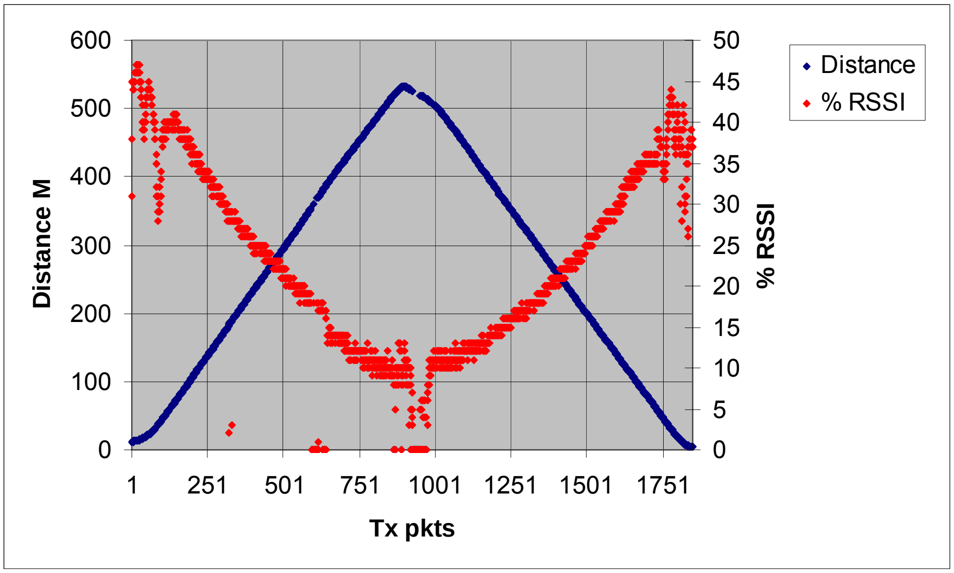


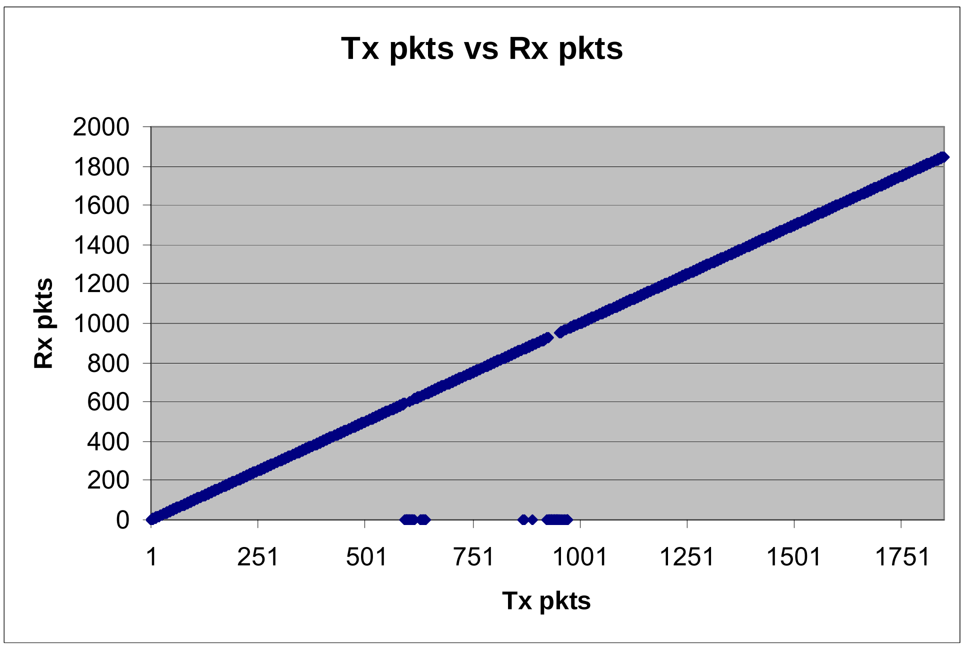


Total packets sent: 2800

Total packets dropped: 209

3.7.1.6 Ford 14 5300 Receiving Vehicle Rear

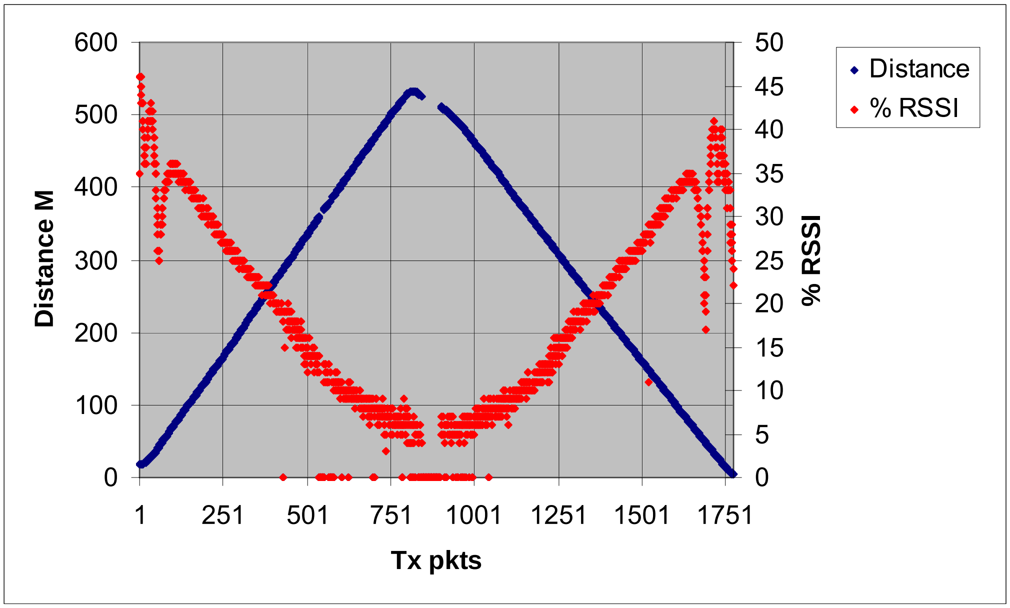


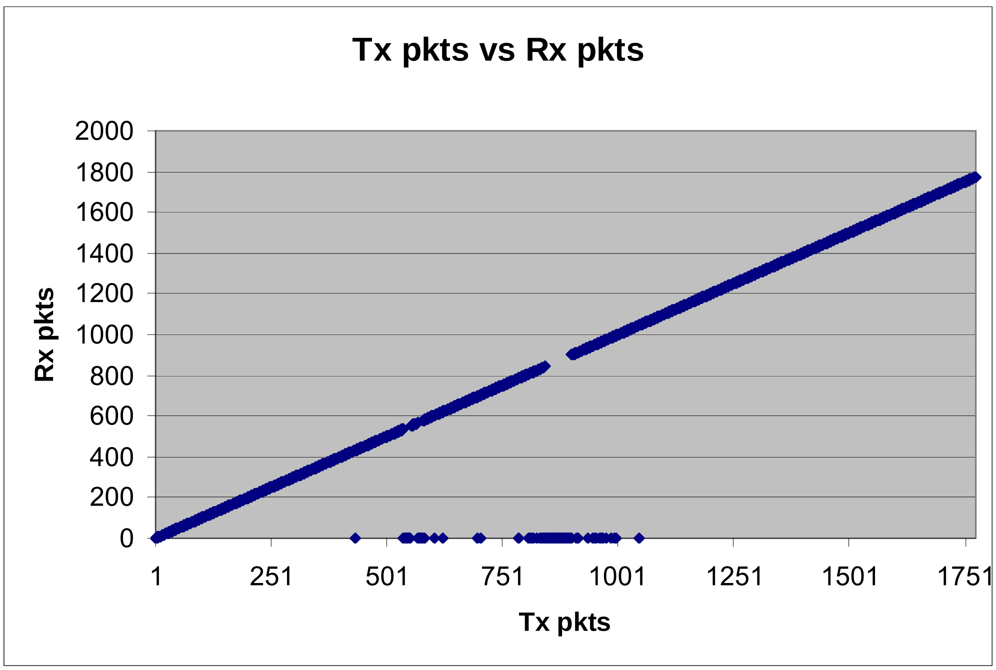


Total packets sent: 1849

Total packets dropped: 69

3.7.1.7 *Ford 15 5890 Receiving Vehicle Rear*

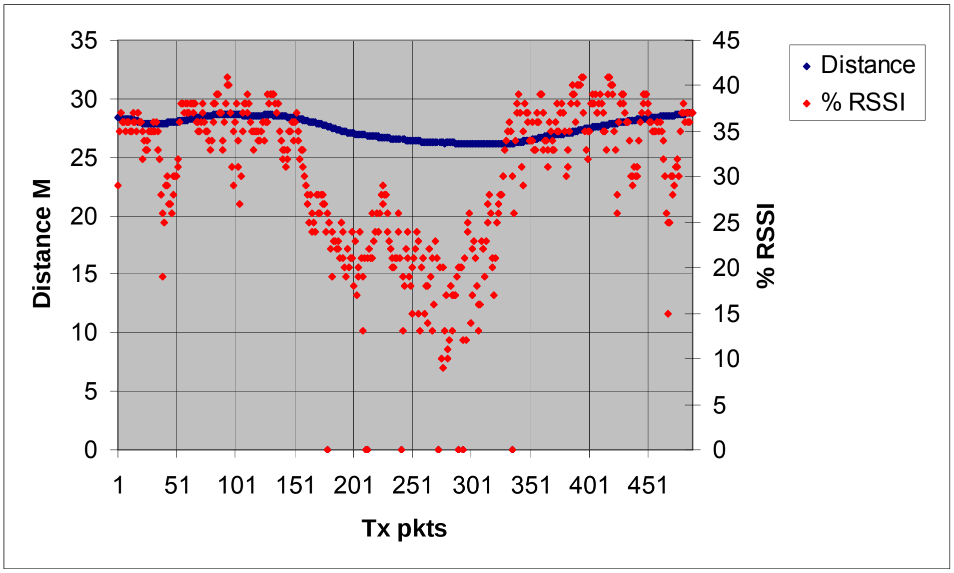


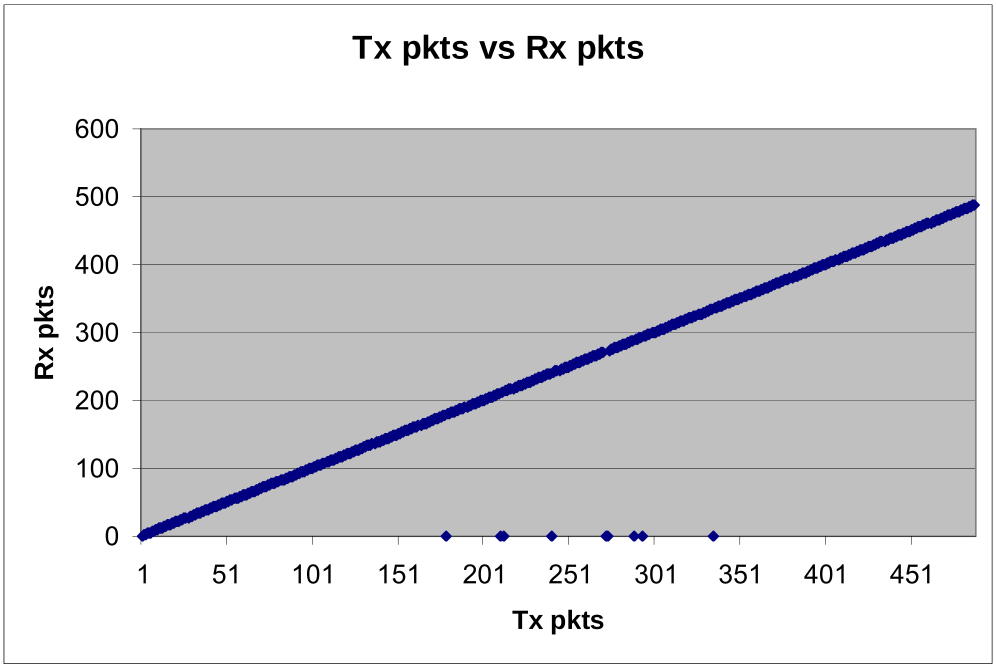


Total packets sent: 1773

Total packets dropped: 119

3.7.1.8 Ford 16 5890 Clockwise Circular Passenger-Side Antenna

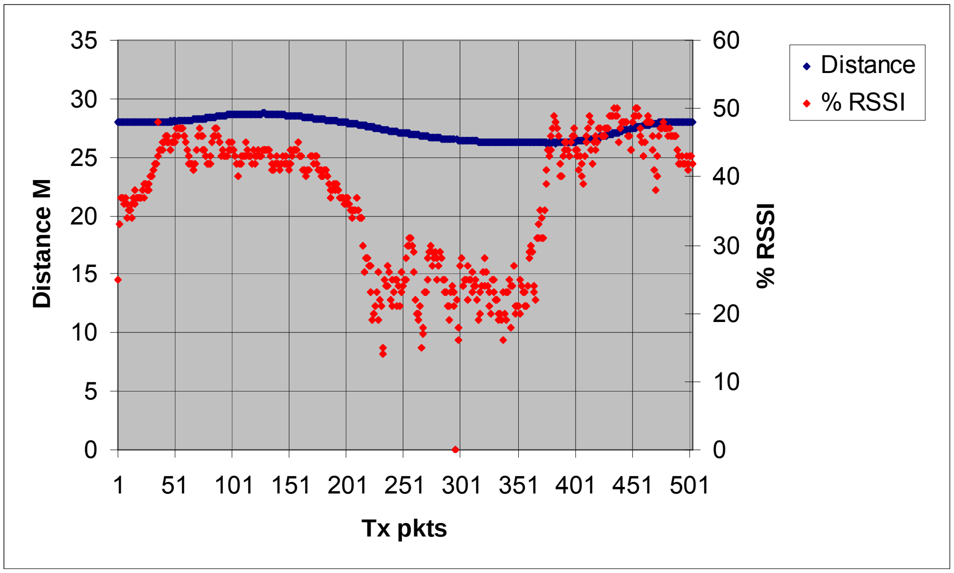


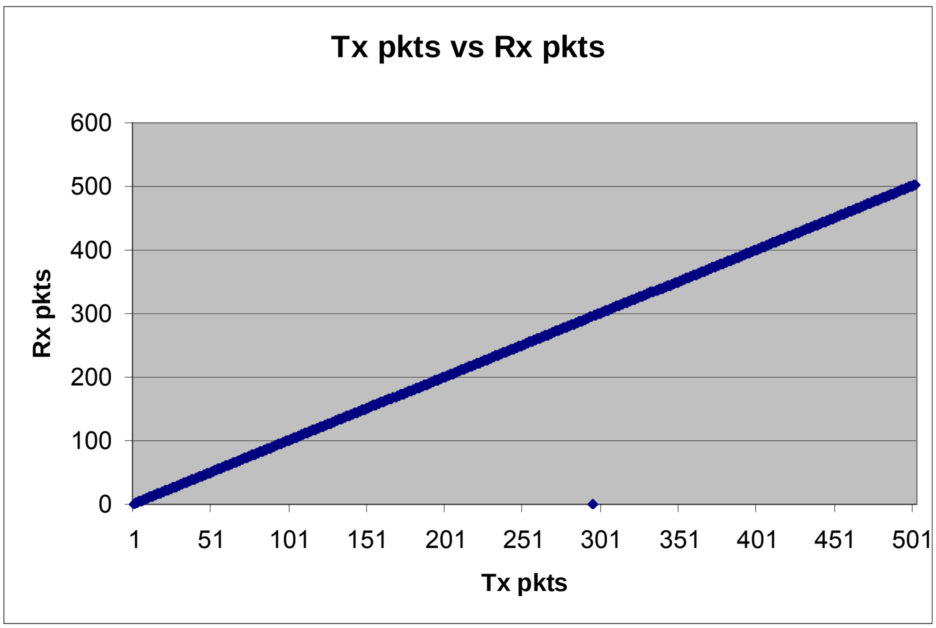


Total packets sent: 488

Total packets dropped: 9

3.7.1.9 *Ford 17 5300 Clockwise Circular Passenger-Side Antenna*

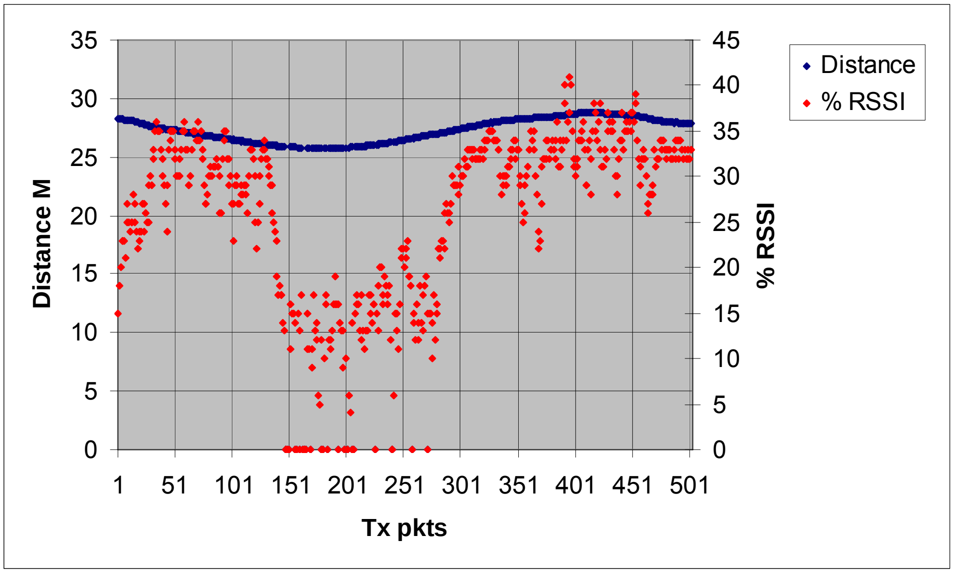


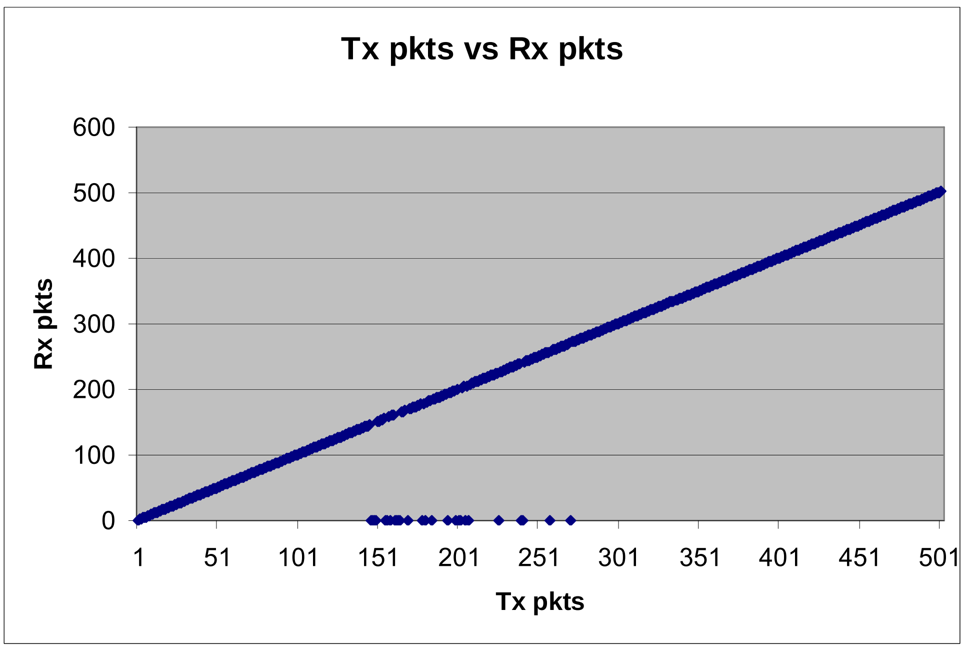


Total packets sent: 503

Total packets dropped: 1

3.7.1.10 Ford 18 5300 Counter-Clockwise Circular Passenger-Side Antenna

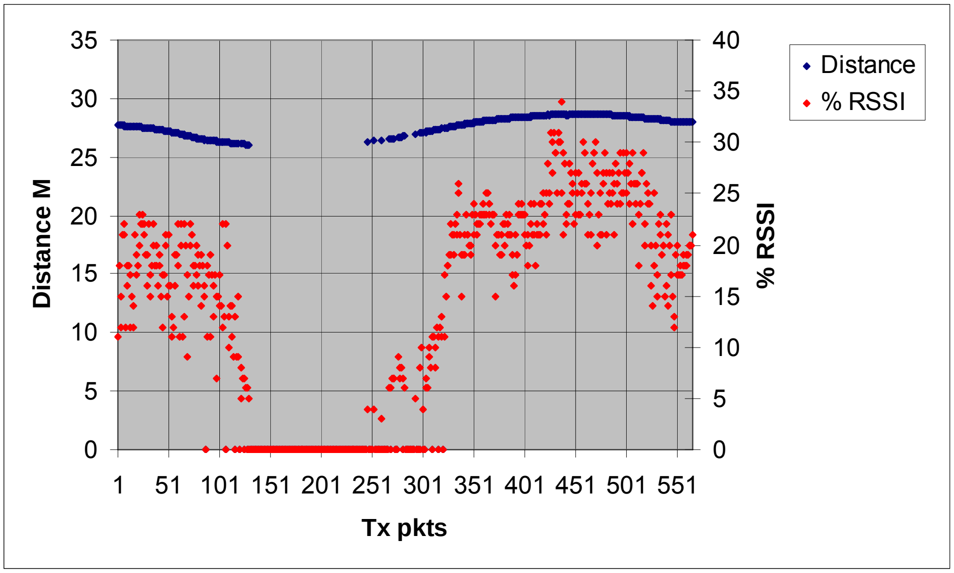


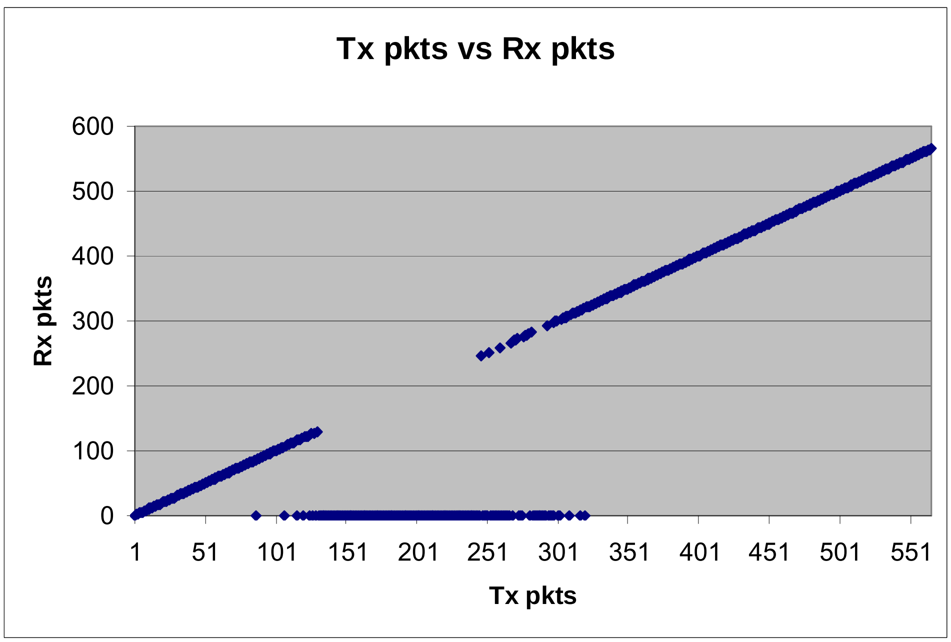


Total packets sent: 502

Total packets dropped: 26

3.7.1.11 Ford 19 5890 Counter-Clockwise Circular Passenger-Side Antenna

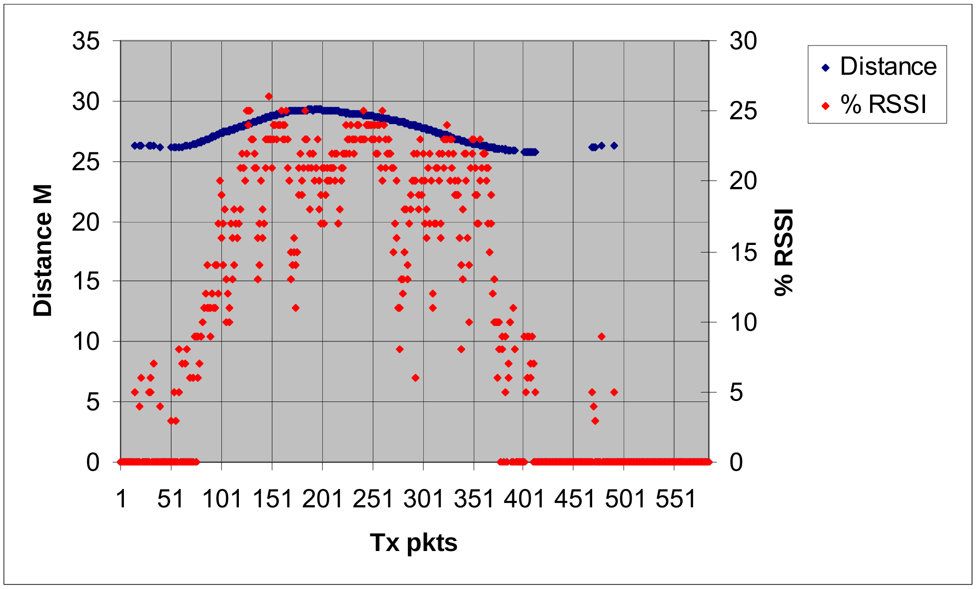


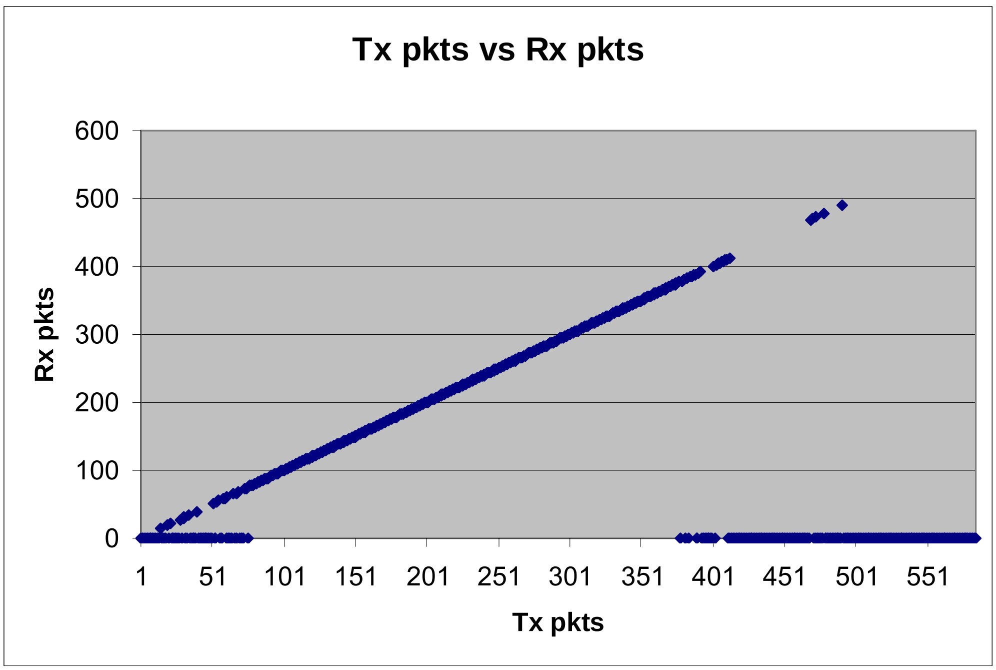


Total packets sent: 565

Total packets dropped: 164

3.7.1.12 Ford 20 5890 Clockwise Circular Driver-Side Antenna

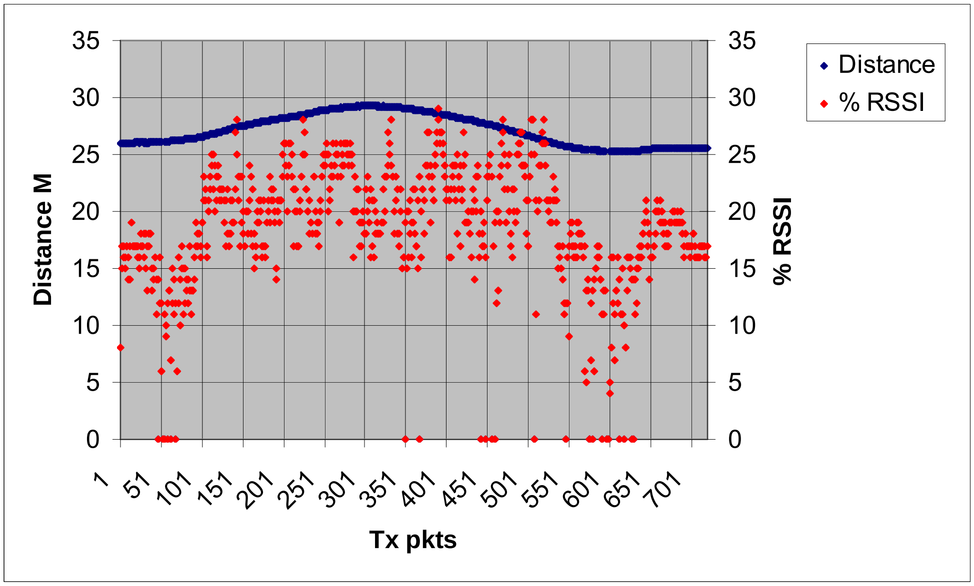


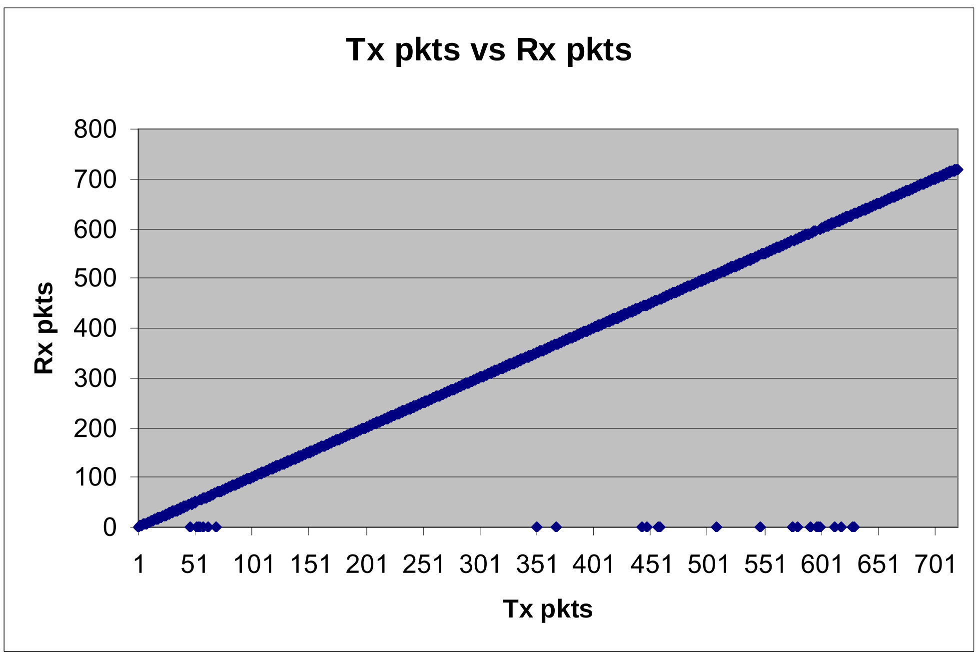


Total packets sent: 584

Total packets dropped: 238

3.7.1.13 Ford 21 5300 Clockwise Circular Driver-Side Antenna

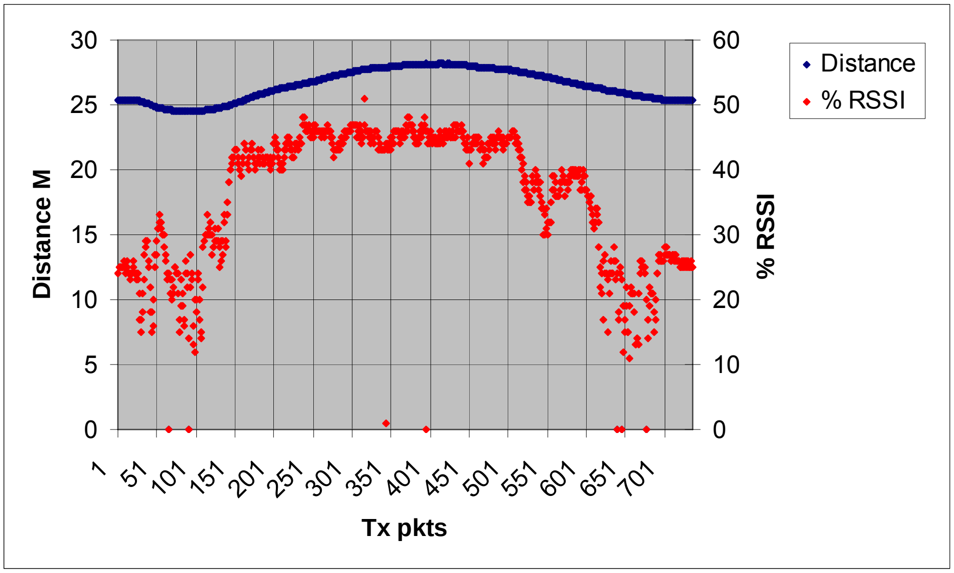


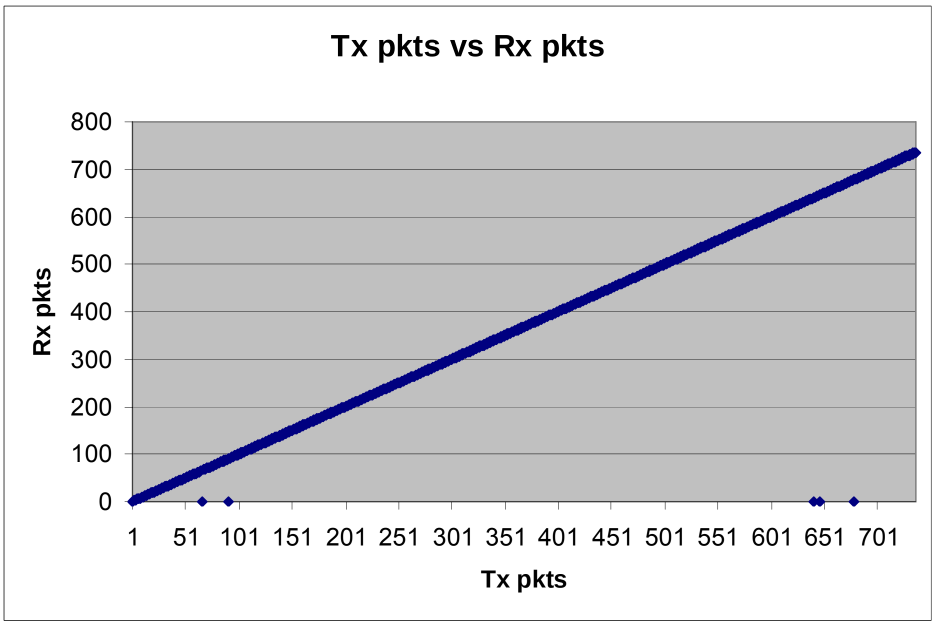


Total packets sent: 720

Total packets dropped: 27

3.7.1.14 Ford 22 5300 Counter-Clockwise Circular Passenger-Side Antenna

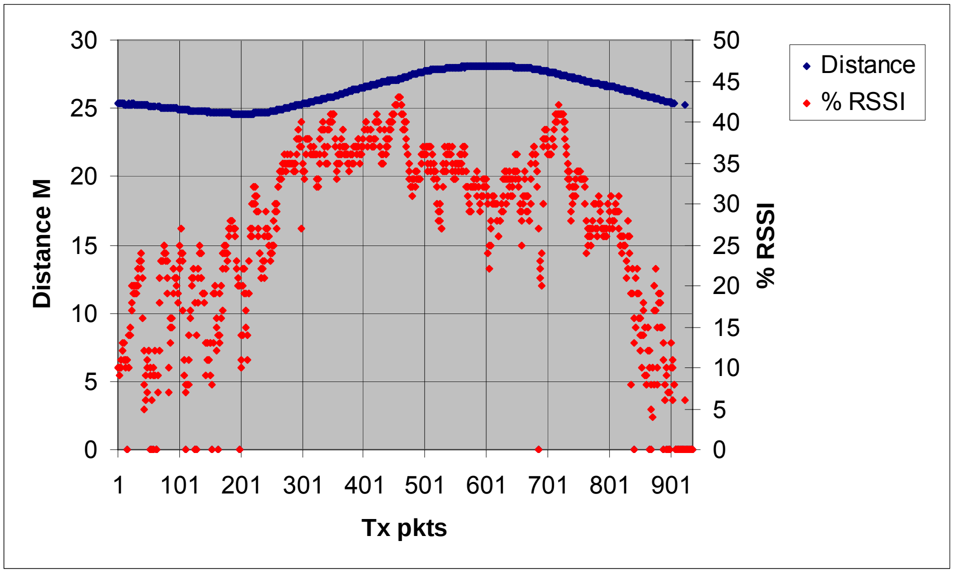


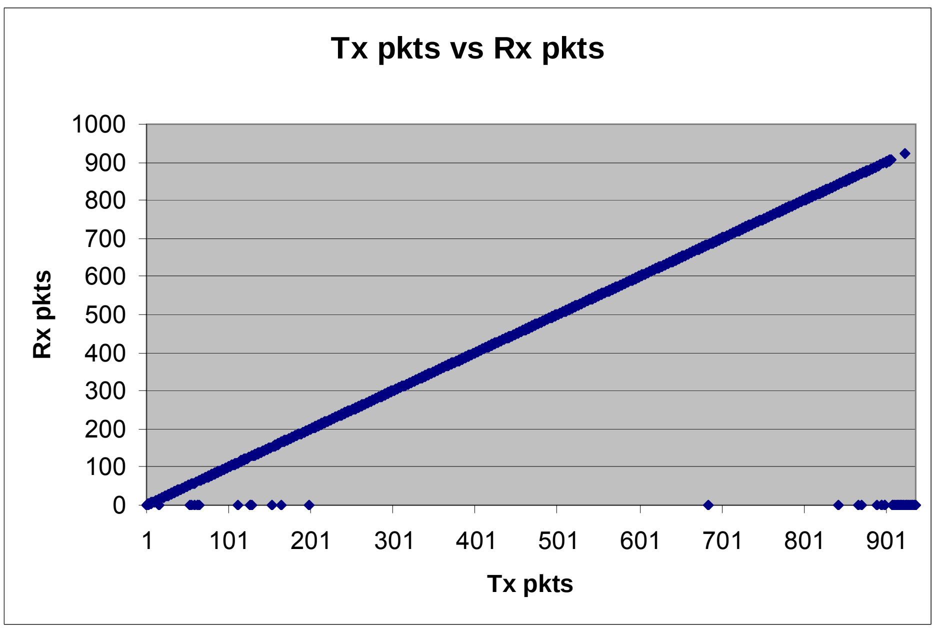


Total packets sent: 736

Total packets dropped: 5

3.7.1.15 Ford 23 5890 Counter-Clockwise Circular Passenger-Side Antenna





Total packets sent: 937

Total packets dropped: 52